THE RECOMMENDATION AND VALIDATION OF AN APPROPRIATE PHYSICAL ASSET MANAGEMENT POLICY FOR PRASA'S METRORAIL DIVISION

by
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Declaration

I, the undersigned, hereby declare that the work contained in this thesis is my own original work and has not previously, in its entirety or in part, been submitted at any university for a degree.

Ek, die ondergetekende, verklaar hiermee dat die werk vervat in hierdie tesis my eie, oorspronklike werk is wat nog nie voorheen, gedeeltelik of volledig, by enige universiteit vir 'n graad aangebied is nie.

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Signature: Date:

Abstract

The decline of the passenger rail transport system of South Africa over the past two decades has left the passenger rail industry in a difficult position. The most significant impact has been the deterioration of the physical assets. Due to the renewed focus by government on passenger rail transport, the need for improving the physical asset management has been recognised.

Physical asset management manifests itself through the application of strategies. The need for new and/or updated strategies was identified and summarily examined. Through the initial literature study, it was found that strategies are founded on the specific maintenance policy of an organisation. The application of the new/updated strategies was intended to take place at Metrorail. An investigation at Metrorail revealed the lack of any significant policy that is required to develop any new strategies. This discovery led to a shift in focus from the development of new strategies to the development of a physical asset management policy.

A generic policy statement called Requirement-based Asset Management (RAM) was developed, with its primary focus being the conducting of maintenance activities based on the requirements of the organisation, the employees, the asset and the customer.

In order to evaluate the suitability of RAM, a strategic roadmap was developed based on the policy statement and validated in three areas of Metrorail. These three areas were the wheel set maintenance system, the Top 7 fault evaluation procedure and the scheduled maintenance cycle of the train sets.

The application procedure concluded that the roadmap and thus by deduction RAM are suitable for the Metrorail environment. RAM can be used to develop/improve an organisation's physical asset management policy.

Opsomming

Die agteruitgang van die vervoerspoorwegstelsel vir passasiers gedurende die afgelope twee dekades in Suid-Afrika het hierdie bedryf in 'n moeilike posisie geplaas. Die mees beduidende impak van hierdie verwaarlosing is die agteruitgang van die instandhouding van fisiese bates. Die regering se hernuwe fokus op die vervoer van passasiers per spoor het gelei tot die herkenning van die behoefte aan verbeterde bestuur van fisiese bates.

Die bestuur van fisiese bates word gemanifesteer deur die toepassing van strategieë. 'n Behoefte aan nuwe en/of opgedateerde strategieë is geïdentifiseer en nagevors. Die aanvanklike literatuurstudie het bevind dat strategieë op 'n organisasie se spesifieke instandhoudingsbeleid gebaseer is en die toepassing van hierdie nuwe en/of opgedateerde strategieë is beplan by Metrorail. 'n Gebrek aan 'n noemenswaardige beleid wat vereis word vir die ontwikkeling van nuwe strategieë is by Metrorail gevind. Hierdie bevinding het 'n fokusverskuiwing tot gevolg gehad – van die ontwikkeling van nuwe strategieë na die ontwikkeling van 'n bestuursbeleid vir fisiese bates.

'n Generiese beleidsverklaring genaamd "Requirement-based Asset Management" (RAM), met die primêre fokus op instandhoudingsaktiwiteite, is ontwikkel en is gebaseer op die behoeftes van die organisasie, die werknemers, bates en kliënte.

'n Strategiese metodologie wat op die beleidsverklaring gebaseer is, is ontwikkel om die geskiktheid van die RAM te evalueer en is dit in drie areas van Metrorail gevalideer. Hierdie drie areas sluit in die instandhoudingstelsel vir wielstelle, die prosedures betrokke by die evaluasie van die sewe mees beduidende foute, en die geskeduleerde instandhoudingsiklus van die treinstelle.

Deur die toepassingsprosedure is die gevolgtrekking gemaak dat die metodologie, en gevolglik die RAM, geskik is vir die Metrorail-omgewing. Die RAM kan dus gebruik word vir die ontwikkeling en/of verbetering van 'n organisasie se bestuursbeleid vir fisiese bates.

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    - Special metion to Shaun Dirks

- And to the Lord God, who through His Son sustains us all, for his mercy and grace that keeps me from falling.

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Glossary

CEO	- Chief Executive Officer
CM/BM	- Corrective Maintenance/Breakdown Maintenance
CMMS	- Computerised Maintenance Management System
ECM	- Experience Centered Maintenance
FMEA	- Failure Mode and Effects Analysis
HR	- Human Resource management
IE	- Industrial Engineering
IRIS	- International Railway Industry Standards
ISO	- International Organisation for Standards
JIT	- Just in time
LTA	- Logic Tree Analysis
MDW®	- Mission Directed Work Teams
OEE	- Overall Equipment Effectiveness
OEM	- Original Equipment Manufacturer
PAM	- Physical Asset Management
PAS 55	- Publicly Available Standard # 55
PBS	- Policy Breakdown Structure
PDCA	- Plan Do Check Act cycle
PdM	- Predictive Maintenance
PM	- Preventative Maintenance
POA	- Plan Of Action
PRASA	- Passenger Rail Agency of South Africa
RAM	- Requirement-based Asset Management
RCM	- Reliability-Centred Maintenance
SARCC	- South African Rail Commuter Corporation
SOE	- State Owned Enterprise
SOP	- Standard Operating Procedures
TDM	- Time Directed Maintenance
TPM	- Total Productive Maintenance
TRE	- Transnet Rail Engineering
WIP	- Work In Progress

1 Introduction

1.1 Background

Infrastructure and logistics form an integral part of the economy of any country. This is specifically true for Africa, and in particular South Africa. [**1**] A significant part of the infrastructure of any country is its rail network. The South African rail network and rail industry had seen a steady decline in the last two decades. The 2010 Soccer World Cup and the energy shortage, experienced in 2008 and 2009, have highlighted the importance of infrastructure. This renewed focus included a focus on passenger rail transport in South Africa, specifically in the Metropolitan areas and has been emphasised by the Gautrain project. [**2**]

The recognition of the need for improvement resulted in the Passenger Rail Agency of South Africa (PRASA) entering into a strategic partnership with the University of Stellenbosch and the subsequent formation of the PRASA Chair in Maintenance and Engineering Management [**3**]. This partnership has led to the identification of many projects that could assist in improving PRASA. One specific focal area is Physical Asset Management (PAM), which forms the foundation for this thesis.

1.2 Research Problem

Initial investigations and negotiations led to a specific interest from PRASA into maintenance strategies. From this, the initial purpose of this study was developed. Research into different maintenance strategies revealed that most strategies depend and refer back to the PAM policy of the specific organisation. [**4**] [**5**] [**6**] [**7**] [**8**] [**9**] The choice of how and when to implement any strategy should be founded and guided in by the specific policy. After extensive examination, it was discovered that PRASA possess no specific PAM policy. [**3**] [**10**] In light of the lack of policy, the focal area of this study shifted towards PAM policies and the development thereof in order to use that policy to then guide the development of PAM strategies. Investigations into literature concerning PAM policies, and the development thereof, revealed two key requirements to develop a suitable PAM policy. [**11**] [**12**] These two requirements formed the research objectives and opening chapters.

1.3 Research Objectives

The two key requirements for the development of a suitable policy are, a thorough knowledge and understanding of PAM strategies, tactics and tasks, together with a comprehensive understanding of the specific organisation and its PAM system. [**12**] [**11**] Based on this, the primary research objective is:

To develop a generic physical asset management policy statement that can be used to derive a suitable physical asset management policy for PRASA and its subsidiaries, specifically Metrorail.

The secondary objectives are as follows:

The focused application of the generic policy statement in PRASA and Metrorail, its subsidiary, through the proposed strategies and tasks, will show its applicability and suitability.

In achieving these two outcomes, the research study will have been successful. To achieve these two objectives, the following goals will have to be realised:

- A comprehensive literature study on PAM policies and PAM strategies, in order to establish the connection between the policy and the strategies that could be derived from it. This will include the following:
    - Research on what the current best practises are with regard to PAM
    - Research into the potential future trends in PAM
- A comprehensive study into the current PAM system at Metrorail, PRASA's primary subsidiary, and the state of PAM within Metrorail
- Developing the generic policy statement and a proposed strategy roadmap derived from the policy
- The application of the derivatives from the PAM policy in three different but linked areas within Metrorail
- Evaluating the application of the PAM policy derivatives, in order to establish the suitability of the PAM policy by implication

The layout of this document takes its structure from the established objectives and goals, starting with the Literature Study and followed by an investigation into the current PAM situation at Metrorail, specifically in the Western Cape. The reason for focusing on the Western Cape, specifically, is its close proximity to Stellenbosch, thus allowing regular site visits and meetings.

The generic policy statement is then discussed. This statement is followed by a discussion of its impact and relevance to different areas within an organisation. The generic policy is then contextualised within PRASA, and specifically Metrorail. Part of this contextualisation is the development and discussion of a proposed strategy roadmap, which is derived from the policy.

The proposed roadmap is divided into two phases, which are each explained. The first phase is expanded on, as the areas of application all form part of this phase. In order to ascertain the suitability of the proposed roadmap, and by implication the generic PAM policy, elements of phase one of the proposed roadmap are applied to three different but linked areas within Metrorail. The three areas all fall under the Rolling Stock department at the Metrorail Salt River depot in the Western Cape.

The thesis concludes with a discussion of the results and recommendations of the three areas and how, based on these, the stated objectives and goals are achieved.

2 Literature Study

The literature study in this thesis is dealt with in two parts. The first part summarises information regarding Physical Asset Management (PAM) policies and the development thereof and explains the need for the second part, which discusses the fields of maintenance and PAM, as well as the concepts and strategies thereof and how these fit together.

2.1 PAM Policies

2.1.1 Definition and Purpose of a Physical Asset Management Policy

The PAM policy (henceforth referred to as "policy" / "the policy") of any company is a written statement that articulates and explains the target or direction and the framework that that company intends to adhere to, specifically for the management of its physical assets. [**4**] [**11**] [**13**]

It needs to provide direction or a target, to ensure that the long-term asset management strategy does not stagnate and cause the company to become ineffective and/or inefficient. If a company is currently unable to perform asset management at a comparatively excellent standard, the policy should provide direction and/or a target for the current PAM system to improve, so as to conform to international standards. [**12**] [**14**]

The framework which the policy should provides gives the PAM system guidance and allows strategies to be developed that complement, enhance and support the mission, vision and values of the company.

2.1.2 Key Requirements for the development of a PAM policy

2.1.2.1 Understanding the company/area within Industry

The first key requirement for developing a policy is to understand and know the company for whom the policy is being developed. This includes investigating the big picture and context in which the company finds itself. It should address where the company has come from, what has led to the current state of the company and more specifically, the state of the current PAM system. This is known as establishing the AS-IS condition/state. [**11**] [**12**]

This involves understanding the vision, mission and values of the organisation and also investigating what the actual conditions and circumstances are on the shop floor. This is achieved by going on site, observing the workings of the company, talking to people and thus not limiting the investigation to the annual report.

2.1.2.2 Understanding PAM and the strategies and concepts within PAM

A large part of the requirements to enable the development of a policy is researching and understanding the field of PAM. A significant part of this document is dedicated to explaining the different concepts and strategies. The reason for this is two-fold: firstly, to provide the reader with an overview of the field and secondly, to establish the basis that the author is working from, along with the credibility of the recommendations made throughout this thesis.

These concepts include, but are not limited to, the following and are investigated in greater detail in subsequent sections.

RCM	Reliability Centred Maintenance: a maintenance strategy that focuses on retaining system functionality. It determines the most suitable maintenance concept and inspection frequency, specifically focusing on the largest contributors to failure. [**8**]
TPM	Total Productive Maintenance: focuses on the operator and maintainer relationship specifically in a production environment, with special emphasis on how to do the maintenance. [**15**]
CM/BM	Corrective Maintenance/Breakdown Maintenance: fixing any un-anticipated fault/failure or breakdown. [**15**] [**8**]
TDM	Time Directed Maintenance: replacing or reconditioning a component/system after a specific time period, based on the Original Equipment Manufacturer (OEM) or historic failure data. [**8**]
PM	Preventative Maintenance: all actions taken to prevent or detect failures; includes TDM, PdM, RTF, DOM. [**9**] [**7**]
PdM/CBM/CD	Predictive Maintenance: maintenance on components based on a concrete inspection that assesses the condition of the assets and can predict its failure. [**9**]
Lean Maintenance	An evolution and improvement of TPM, based on Lean Manufacturing principles. [**16**]
DOM	Design-Out Maintenance: the action whereby the asset/asset components are redesigned and replaced, specifically to remove a fault. [**8**] [**17**]
RTF	Run to Failure (operation until failure or breakdown): a maintenance technique applied to assets/asset components where any other strategy is neither viable nor feasible and the health, safety and environmental impact is unacceptable. [**8**]
PAS 55	Publicly Available Specification number 55 from the British Standards for optimised management of physical assets and infrastructure. It provides definitions and requirement specifications for joined-up, whole-life asset management [**4**] [**11**]
IRIS	The International Railway Standards Institute: its sole purpose is to develop standards for the Railway Industry from the supplier to the operator. It is fully compliant with the International Standards Organisation (ISO) specifications and by applying for IRIS certification, ISO is included automatically. [**18**]

Table 1 PAM maintenance concepts, strategies and standards

2.1.2.3 Policy Review and Update

The final key aspect of developing a policy is setting up a review procedure, by which the suitability of the policy is established and updates or revisions can be made. As technology improves and maintenance techniques evolve, so too must the policy. If the organisation has achieved all the targets set out by the policy or the targets are no longer relevant, then the policy needs to be reviewed and updated. Only then can the trap of doing maintenance based on an "it's how we have always done it" attitude be avoided. Although a full review is not required every year, it is still advisable, so as to ensure that the policy serves its purpose. [**11**] [**13**] [**8**]

2.2 PAM strategies and concepts

2.2.1 Failures and failure modes

Before looking at all the different strategies and techniques that exist, one first needs to understand the fundamental principle of failures. A failure occurs whenever a system, sub-system or component no longer operates within the expected or designed specification. This includes all breakdowns and stoppages of any part of the operation/service, and also when the operation is not performing at an expected level. Traditionally, the term "failure" has been limited to a breakdown and not also to out-of-specification performance. [**8**] [**9**]

Failures can generally be grouped into six distinct patterns or profiles. Each profile is based on the age-reliability correlation for components, where the number of failures is plotted against the age of a component/equipment. To illustrate each profile, a graph is provided which is followed by an explanation in the paragraph below the graphs.

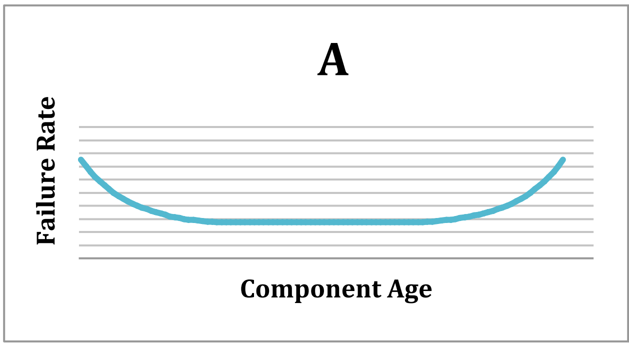

Figure 1 Graph A describes a high initial failure rate, followed by a random failure rate and concluding with a pronounced wear-out region. It is also known as the bathtub curve.

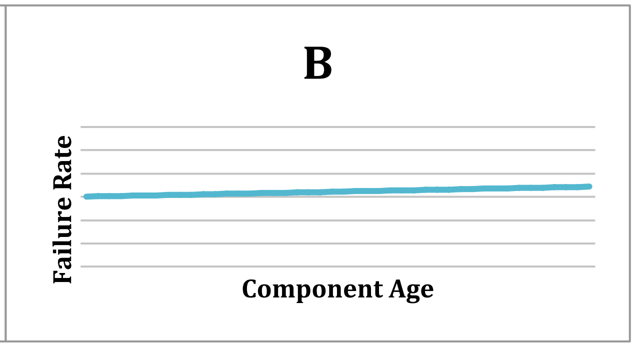

Figure 2 Graph B describes a gradually increasing failure probability, without an identifiable wear-out region.

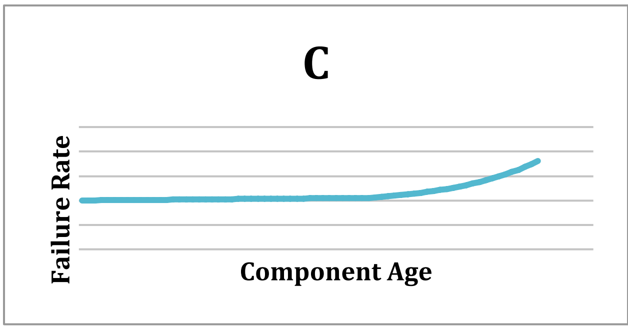

Figure 3 Graph C represents a constant or gradually increasing failure rate with a pronounced and-of-life wear-out rate.

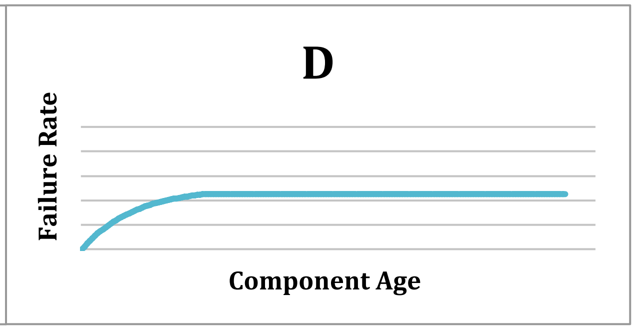

Figure 4 Graph D shows a low initial failure rate when the component is new which then climbs to a steady random failure rate.

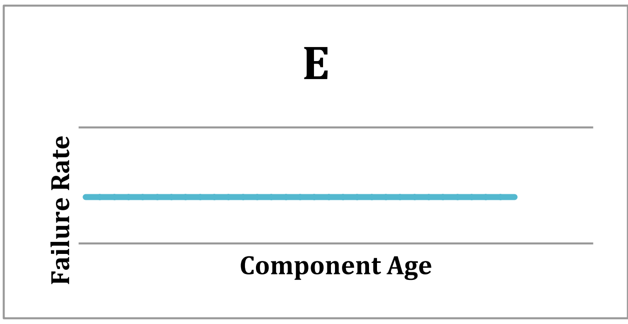

Figure 5 Graph E represents a constant probability failure rate at all ages.

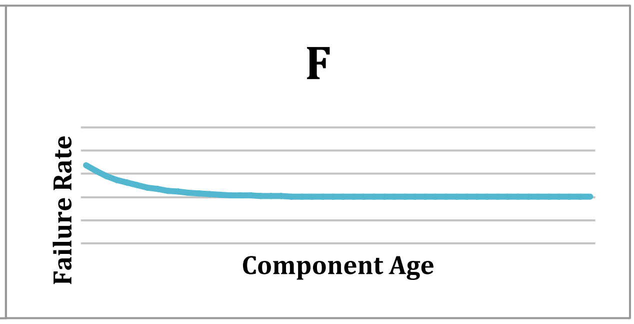

Figure 6 Graph F describes a high initial failure rate that settles to a random failure rate.

These six figures represent the most common combinations of failure probabilities across different industries. [8] The ratio between these probabilities varies from industry to industry and specifically between different components. It was found that the most common age-reliability pattern is figure F, where the initial probability of failure is high and then decreases to a lower constant probability. Traditionally, it was expected that most failures were age-related and that a time-directed or condition-directed maintenance strategy would be best suited to decreasing the number of failures. However, research in different countries and different industries has shown that the most common failure patterns are actually not age-related, rather they generally fall under figure D, E or F. In each of these cases the reliability of a component does not decrease with age. After an initial increase or decrease, the failure probability stays constant. [**8**] In three different studies of large populations it was found that more than 75% of all age-reliability/-failure relationships are represented by graphs D, C and F.

The different age-failure relationships have a significant impact on choosing which Preventative Maintenance (PM) strategy to adopt. The suitability of each strategy to Figures 1-6 is discussed in the relevant sections. [**9**]

2.2.2 Corrective Maintenance/Breakdown Maintenance

Corrective Maintenance/Breakdown Maintenance (CM/BM) refers to all unexpected/unplanned maintenance that occurs after an unplanned failure has occurred. It is sometimes also referred to as reactive maintenance. To understand this better, one needs to understand the concept of a failure first. A failure does not exclusively refer to a breakdown where the function of a component or system has stopped. Rather, it also includes any performance or function that occurs outside of the required specification. Any failure detection that occurs outside of a planned PM task, including inspections, thus forms part of CM/BM, even if the action prevents a larger failure. In many cases the failures themselves are and can only be detected once the failure causes an interruption in the normal operating condition of a system, which is generally referred to as a breakdown. [**9**] [**8**] [**7**]

CM/BM is an unplanned procedure for restoring the system back to its normal operating procedure, thus it is not formalised and does not have a Standard Operating Procedure (SOP) along with the replacement parts required [**17**]. There are different ways of understanding and defining CM/BM. Many argue that any action that prevents a breakdown is preventative, and that the conscious decision, after a formal investigation, to operate equipment until it fails, is corrective. [**8**] For the remainder of this thesis, CM/BM will not be understood in this way. Instead it will be understood as stated in the opening line of this section, i.e. as all unexpected/unplanned maintenance that occurs after an unexpected failure has occurred. The decision to allow equipment to operate until it reaches a failed state is known as a Run To Failure (RTF) strategy. RTF is discussed in greater detail in section 2.2.4. Some of the advantages and disadvantages of CM/BM are listed below.

2.2.2.1 Advantages and Disadvantages of CM/ BM

Advantages	Disadvantages
Part/equipment life can be maximised	Breakdown can cause damage to other parts
No inspection costs are incurred	Cost to environment is increased
Administrative costs are reduced, as the system is self-sufficient [17] [7] [8]	Risk of injury is higher
	Cost of unplanned downtime
	Downtime is longer
	Stress due to emergency status
	Lost opportunity cost due to lost production/service
	Unplanned downtime causes loss of customer confidence
	Cost of emergency administration [8] [17] [7] [9]

Table 2 List of Advantages and Disadvantages CM/BM

2.2.2.2 Why and/or when CM/BM is used

There is only one reason for using a CM/BM system. CM/BM is used because it is the default that an operation reverts to if no planned/structured maintenance takes place or if planned maintenance is not performed properly. An illustrative example of this is not regularly applying grease to bearings that require grease. The bearing will wear out and fail or seize, halting that piece of equipment. In this instance regular greasing is a form of planned maintenance. [17] [8]

2.2.3 Preventative Maintenance

Preventative Maintenance (PM) is a series of tasks that are performed at a frequency, based on a schedule that is governed by different measures. These tasks are performed to achieve one or more of the following three outcomes:

- Extend the life of an asset and/or
- To detect critical wear and/or
- To predict a failure or breakdown. [17] [7]

PM includes any planned action that prevents or identifies a failure. Some of the measures that govern the frequency are time (in terms of hours, days and weeks), production volume, machine hours, distance travelled and condition of components and parts. [9]

A more simplified explanation of PM is that it is the opposite of CM/BM, in that any planned action that is taken throughout any aspect of an organisation to decrease failures or remove the possibility of failure can be considered PM. All PM actions are performed for one or more of the following three reasons: (1) to prevent or mitigate the onset of a failure; or (2) to detect the onset of a failure; or (3) to detect a hidden failure. [**17**]

Traditionally, PM was, and sometimes still is, understood as checking everything all the time. This is not the case. If it is implemented with this understanding, it will lead to great cost, effort and frustration, as it will be ineffective. Just like any other strategy within an organisation, PM needs to be effective and efficient. [**7**] [**8**]

There are four distinct categories of PM: Run-To-Failure (RTF), Fault Finding (FF), Time Directed Maintenance (TDM) and Predictive Maintenance (PdM). All other strategies, techniques and concepts consist of one or more of these four basic elements. No matter how different the strategies might appear and regardless of the terminology that it uses, each strategy will still be based on one or more of these basic elements. Each of these elements is discussed in its own section within this chapter.

The inspection process forms part of each of the four categories of PM. Deciding what to inspect and how often to inspect it forms a large part of the setting up and the operation of any PM system in an organisation. The frequency of inspection should ideally be based on sound statistical calculations that are derived from the failure characteristics of each component/sub-system/system. [**9**] However, in many instances, the frequency of inspection and the tasks of which inspections consist are not derived statistically, but rather intuitively or simply because they have always existed. This is often the case when sound failure data does not exist or is unavailable.

2.2.3.1 Advantages and Disadvantages of PM

Advantages	Disadvantages
Allows for planned/structured downtime. Downtime can be planned into the production schedule	High initial implementation cost
Can decrease the number and frequency of breakdowns	Results are delayed (the system requires time to reach new equilibrium)
Can cut costs by only replacing/repairing the part and not the damage caused by breakdown	The monetary savings of prevented shut downs are not always quantifiable
Allows for financial planning and consistency. Better budgeting ability	Higher level of training required from technicians and operators
Fewer instances of downtime	Extra administration required to facilitate the system
Decrease wear	Downtime for inspection is required, thus more frequent downtime
Reduce costs by reducing emergency repair	Risk of secondary damage due to inspection/repair/replacement is higher
Lower the risk of injury and damage to environment **[9] [17] [8] [7]**	Does not eliminate unplanned downtime completely
	Needs involvement from senior management as well as other support departments (HR, Finance, Operations)
	It is a long-term program that requires a shift in mind-set from all levels
	Can easily revert to CM/BM if not implemented correctly
	The risk of breakdown due to the inspection is higher
	Parts life is not maximised **[7] [8] [17] [9]**

Table 3 Advantages and disadvantages of PM

2.2.4 Run-To-Failure

Run-To-Failure (RTF) is a specific form of preventative maintenance that does not actually prevent a failure from occurring. **[8]** **[17]** **[9]** It is the conscious decision to allow equipment to operate until it reaches a failed state. It forms part of preventative maintenance because it is a strategy that is applied when no other strategy is suitable or possible. It is and should only be applied under special pre-determined conditions. The conditions for implementing RTF are as follows:

- If the safety and/or the environmental impact is negligible or non-existent and
- if the impact on any availability is negligible and/or
- if the cost of any other strategy is higher than the Return on Investment and/or
- if the state of the component/system is undetectable/immeasurable and/or

- if the failure rate is random.

The distinction between CM/BM and RTF is important when recording the fault and assigning the cost to either PM or CM/BM, although the actions in both cases can be completely identical. This distinction becomes significant when the cost and viability of the specific PAM program or strategy are calculated. The correct allocation of costs and cost savings to both CM/BM and PM are also very important, as they allow for a realistic and accurate review and update of the maintenance policy. If a planned inspection (thus part of the PM program) discovers a fault, the financial implication needs to be credited to PM, even though the action that needs to be taken is corrective in nature. [**8**]

If a RTF strategy is not possible due to one of the stated pre-conditions and if TDM or PdM actions are too expensive, a fourth alternative exists. It is known as failure-finding and is discussed in section 2.2.7.

2.2.5 Time-Directed Maintenance

Time-Directed Maintenance (TDM) is the third of the basic elements that make up any PM program, strategy or concept. TDM is any maintenance action that takes place based on a measure of time, be it clock time, calendar days, seasons of the year, number of cycles, number of kilometres, etc. [**7**] [**17**] In each of these cases, the time in operation is measured in some form or another. TDM includes any inspection that takes place, as well as any intrusive maintenance, where the component or piece of equipment is opened up. [**9**]

Unless it is an inspection, TDM is generally an overhaul type operation, where components are replaced or reconditioned after a given period, thus resetting the effective age of a system. All time-based inspection cycles form part of TDM, even if they measure the actual condition of a component or system. In some literature, TDM is specifically broken down further in these two tasks. An inspection task is referred to as only Time-Directed (TD) and any task that opens up a piece of equipment is referred to as a Time-Directed Intrusive task (TDI). [**6**] [**19**]

Traditionally, the majority of PM was time-directed in nature. With the increase in computerisation and automation, a shift from TDM to PdM is occurring. This shift is explained in full detail in the next section (2.2.6). It has also been discovered that in many instances where TDM was prescribed, the intervals of both inspection and overhaul/replacement have been too short. It is understandable that safety urges caution and thus conservative intervals. It has been discovered that in many cases a safety factor of 100% or more exists. This means that TDM tasks are sometimes performed twice as often, if not more often, than they should.

In table 4 below are some of the specific advantages and disadvantages of TDM. Most of the PM advantages and disadvantages still apply and have not been added again.

Advantages	**Disadvantages**
Is simpler to administrate than most PdM tasks (interval calculation can be a once-off)	Inspection and overhaul/replacement frequency could be higher or lower than required. Both are costly
TDM capital costs can be lower than PdM capital costs	Often applied as a fall-back if no PdM task is available, without proper scientific investigation
TDM requires lower skill level than PdM **[8] [7]**	PdM can be cheaper than TDM over the life of the component/equipment/system [**17**]

Table 4 Advantages and disadvantages of Time-Directed Maintenance

2.2.6 Predictive Maintenance

Predictive Maintenance (PdM) is any maintenance action that determines the condition of a component/piece of equipment/system so that it can be replaced before it fails. Unlike TDM, PdM is not based as heavily on statistics and historical data. From the outset, PdM is based on actual measurements and readings. It is also known as condition-based maintenance, or condition-determined maintenance. [**17**] [**6**]

PdM is growing in popularity. It is being implemented increasingly within PM, but it is also helping to decrease CM/BM elements of maintenance. The rapid development of sensor-based measuring technology is the prime contributor to this growth. Modern machinery, equipment and tools are increasingly being developed to include condition-monitoring technology from the outset. Computer- and IT-related technology in particular have contributed greatly to continuous monitoring. With the ability to monitor the condition continuously comes the ability to predict when failures will occur. PdM has an advantage over TDM in that the life of the components/system can be maximised.

PdM has one distinct disadvantage though, that it is very costly to implement. The Return on Investment (ROI) of PdM often makes it unviable even if the technology to assess the condition already exists. [**8**] If a system is operating purely on a PdM basis, the amount of downtime will not be decreased, because every time a component approaches the end of its life, the system has to be stopped to allow for replacement or overhaul of components within the system. Most maintenance actions and strategies are a combination of the four basic PM strategies. [**9**]

Advantages	Disadvantages
The downtime is less than generic PM, costs are saved	The condition of the components may not be measurable
Part life is maximised	The cost of measuring can outweigh the cost benefit
Unplanned downtime is lower than with generic PM	Specialized equipment may be required to perform measurements. Thus, specialized operators of the equipment may also be required
Secondary Damage (Damage caused to other parts while a part is replaced/repaired/inspected) is reduced	Automated monitoring requires higher capital expense
Lowers cost of parts and labour compared to time based PM	The condition of equipment might not relate to the expected failure
All the other advantages of generic PM apply [9] [17]	All disadvantages of PM to varying degree also apply [9] [8]

Table 5 Advantages and disadvantages of Predictive Maintenance

2.2.7 Failure-Finding

In PM, all inspections are a combination of TDM and PdM. The inspection frequency is determined by a form of clock/time measurement (a TDM task), whereupon the condition of the item is established and the failure is predicted (a PdM task). In each case, these actions should lead to the detection of failure or the expected onset of failure. [8]

Not all failures can be detected in this way. Some failures remain hidden during the normal course of PAM operations. Because of this they are easily overlooked when it comes to scheduling PM tasks. These hidden failures predominantly occur in systems that do not form part of normal operations. Some examples of these are backup systems, equipment that is used infrequently and emergency systems. In this case a specialized version of inspection is used, called failure-finding (FF). FF is the act of inspecting and testing specifically those items that are not part of the normal operations. In addition, FF is normally limited to checking if a system does or does not work, rather than assessing the full condition. In some cases FF activities take place based on a clock/time interval, specifically for backup and emergency services. In other cases, such as with infrequently used equipment, the inspection only takes place shortly before intended use. [6]

FF is specifically used when dealing with equipment or systems that need to function infrequently, but immediately when required. In this case, the cost of a full TDM or PdM strategy outweighs the benefits derived from the TDM or PdM tasks. Although RTF is often used as the alternative to TDM and PdM, the importance of the equipment in these cases is still too high for a RTF strategy to be implemented. [8]

2.2.8 Reliability-Centered Maintenance

Reliability-Centered Maintenance (RCM) is a specific implementation strategy of PM. [**8**] It aims to preserve the function of a system as a whole and not each and every part. An example within the Railway Industry is that a train set continues operating even if some of the cabin lights do not work in the coaches. To achieve this, RCM focuses on identifying and monitoring specific failure modes (causes of failures) on specific parts or equipment that are essential to keep the system functioning. Based on this information, the RCM system then prioritises and ranks the failure modes of the system components that are critical to preserving system functionality. The final aspect of RCM is only then to select the applicable and effective PM practices. [**17**] [**16**]

There are four features that define RCM:

1. To preserve functions.
2. To identify failure modes that could defeat the functions.
3. To prioritise function need (via failure modes).
4. To select applicable and effective PM tasks for the high priority failure modes.

Preserving functionality is the first and most important feature of RCM. [**8**] Instead of viewing each piece of equipment or each component separately and thus maintaining them separately, equipment is viewed as part of a system. The benefit of a system functionality-based view becomes apparent in the following hypothetical illustration:

> A railway operates two equidistant dual sets of lines. In the first set, each line can carry 100% of the required capacity, but in the second, each line can only carry 50% of the required capacity. However, there are only funds available to maintain one set of lines preventatively. From a traditional perspective on PM, each line needs to be maintained, but financially this is impossible. When viewing these two sets of lines functionally, it becomes apparent that all the resources need to be dedicated to the set of lines with 50% carrying capacity. If one of the lines in the other set become inoperable, the operable line can carry all of the capacity while repairs are being done. This scenario is not sustainable though, as both 100% lines will gradually deteriorate and no longer be operable.

The second feature of RCM is the identification of failure modes that could defeat the ability of a system or sub-system to perform its function(s). [**8**] A failure mode is the way or the reason why a system fails. As has been described in section 2.2.1 regarding failures, there are different types of failures. In some cases there is a complete breakdown, while in others the productivity or quality decreases. Failure mode identification is made up of two parts. First, there is identifying functional failures, i.e. failures that cause the system to no longer deliver its function. Based on this, the second part is the identification of specific failure modes within the system. To achieve this, each component of each piece of equipment is meticulously examined in order to define exactly how that component might fail. [**17**] [**9**]

RCM's third feature involves the prioritisation of all failure modes for the specific allocation of budgets and PAM strategies to different components in the system, based on the failure mode and its effect/impact on the system to deliver its function. This is done by filtering each failure mode through a three-stage decision tree, which divides each failure into one of four categories. [**8**]

The final feature is the assignment of a specific PM strategy, i.e. TDM, PdM, RTF or FF, as has been discussed in the relevant forgone sections. For each component, the strategy with the highest effectiveness and efficiency is assigned. [**20**] Effectiveness means that the task assigned will achieve one or more of the three reasons for assigning a PM action as defined in section 2.2.3. In short, effectiveness means doing the right thing to create the most value. Efficiency is defined as doing something at the lowest possible cost, where cost is not only viewed in monetary terms, but as all inputs, as well as wasted output. To phrase it simply, efficiency is doing the right thing well.

To achieve these four features, a nine-step (7+2) plan was developed. [**8**] This process is as important as the four features of RCM. Each of these nine steps is defined, below followed by a brief explanation.

Step 1: System selection and information collection.
Step 2: System boundary definition.
Step 3: System description and functional block diagram.
Step 4: System functions and functional failures — Preserve functions.
Step 5: Failure mode and effects analysis (FMEA) — Identify failure modes that can defeat the functions.
Step 6: Logic (decision) tree analysis (LTA) — Prioritise function requirement via the failure modes.
Step 7: Task selection — Select only effective and efficient PM tasks.

These seven steps form the basis of the RCM process and contain all four features of RCM, as will be shown. [**8**] The following two steps are specifically included for continued success of RCM implementation

Step 8: Task packaging — carrying the recommended RCM tasks to the shop floor
Step 9: Living RCM program — comprising the actions necessary to sustain the beneficial results of steps 1–8

Each of the nine steps comprises one or more element(s). For each step these elements are briefly discussed below, as they contribute to the overall understanding and RCM as a PAM strategy. [**8**]

Step 1 consists of three elements, the first of which is deciding at which level of assembly to perform the RCM analysis. There are generally four levels. They are part level, component level, system level and plant level. Most PM strategies focus on the part- or component level. However within RCM the focus should be at a systems level. Thus, whenever possible, the RCM analysis should be performed at a systems level with reasonable exceptions for components and down to the parts level if necessary. The second element is the system selection. This is done by applying the Pareto principle, which is also known as the 80/20 rule. According to this principle, 80% of the failures and downtime can generally be attributed to 20% of the systems. It is this 20% to which RCM should be applied first. Finally all existing information about that 20% of the systems is gathered as the last element of step 1. This information includes: drawings, any and all relevant manuals, Standard Operating Procedures (SOP), system specifications, and history of equipment within the system.

Step 2 has only one element, namely boundary selection. Boundary selection is the accurate definition of what constitutes the system and what does not. Accuracy is important in this regard for two main reasons. The first is to make sure that there is no overlap or exclusion of any equipment with/between other systems. The second is that an accurate boundary definition helps to determine all the system inputs and outputs. [**8**]

Step 3 consists of five elements that all insure that the system is understood and viewed correctly, based on the information from the first two steps. The system is described, functional block diagrams are created, input-output interfaces are finalised, and a system work breakdown structure is created. Finally, all equipment history is consolidated. [**8**]

Step 4 involves two elements that are interlinked. First, all system functions need to be defined correctly so that secondly, all possible functional failures can be determined and defined. [**8**]

Step 5 has three elements. These three elements together define all the causes of the functional failures by investigating the system. The first element is that of creating an equipment failure matrix, which is similar to a house of quality. An example of each (equipment failure matrix and house of quality) is provided within the RCM Appendix A. At every intersection of the matrix a Failure Mode and Effects Analysis (FMEA) is performed. A FMEA is an analysis of how each failure is caused or what caused it, as well as an explanation of what effects it can have, which includes any indirect effects. During the FMEA, all failure mode overlaps are removed. A failure mode overlap is when the same cause creates more than one failure. The final element of step 5 deals with redundancy within the system. Herein a decision is taken on how to treat system components that are redundant. [**8**]

Step 6 is the Logic Tree Analysis (LTA) where, based on a decision tree (appendix A), all of the remaining failure modes are classified into three categories, within which they are classified in turn as normal failures or hidden failures. The first category is the safety and environmental category, the second is the outage category (where a failure will cause a disruption to system functionality) and the last category is the minor impact category. These categories exist in order to enable further prioritisation of maintenance action, which is especially critical with a limited budget.

The final primary step involves listing the appropriate maintenance tasks/strategy for each failure mode and then choosing the most effective and efficient one. The tasks and/or strategies chosen are based on the four elements of PM, which are TDM, PdM, FF, RTF. The task selection roadmap is included in Appendix A. Finally, step 7 is completed by performing a "sanity check" on each assignment of a PM task or strategy. A "sanity check" involves a short revision of the tasks chosen in order to make sure that no fundamental mistakes have been made.

Task 8 is self-explanatory, but due regard needs to be shown to this task in order to make implementation as successful as possible.

Task 9 involves steps to create a structure to continuously evaluate the RCM program, and to allow it to adapt and evolve to new and other requirements within the organisation.
Two specific aspects of a living RCM program include interval evaluation and age exploration. The basic premise behind these two is that both the inspection interval and equipment age boundaries need to be pushed in order to maximise the Return On Investment (ROI) of the PM programme. This is done both statistically and intuitively. [**8**]

A full, classical RCM programme requires a significant financial investment. For the remaining 80% of the organisation's physical assets, there are two derivations of the RCM programme that are financially appropriate and faster. They are the abbreviated RCM program and Experience Centred Maintenance (ECM). Abbreviated RCM retains the four key features of RCM but the 7-step process has been reduced, with step 8 and 9 remaining the same. ECM is a radically shortened, 3-step process that should only be used for "well-behaved" systems, which are systems that have few faults and perform as required. [**8**] [**9**]

The last aspect of RCM does not form part of the nine steps. It is called Items of Interest (IOI), where an item of interest is an idea, observation or recommendation that is made concerning the organisation, but does not strictly form part of maintenance. IOI's are normally by-products of the RCM program that come about during the steps of RCM. The thorough system analysis that occurs during the RCM program results in better understanding of the system and that in turn results in solutions and improvement ideas for the system. To illustrate this, consider the following example: If during step 3, where the equipment history is consolidated, it is discovered that an SOP is missing or no longer up to date, an item of interest is generated. This IOI is then considered and possibly implemented. The benefit derived from this IOI should thus be credited to the RCM program. The initial costs of many RCM programs have been recovered purely through IOI, even before weighing the benefit of the PAM improvements. IOI benefits have been separated into five distinct groups or areas of impact. They are listed below and then explained in greater detail.

- Operational impact
- Safety impact
- Logistics impact
- Configuration impact
- Administration impact

Where an operational impact influences which operations and tasks are performed by the company, a safety impact highlights areas relating to safety. Logistics impacts are impacts that affect the supply chain of the core organisational functions. The configuration impact deals with effects relating to the process, which deals with adding, removing or improving components and sub-systems. The administration impact relates to the IOI's that directly influence the administration functions of the organisation. [**8**]

The nine-step process and the items-of-interest form part of the greater RCM program and many of the advantages and disadvantages of RCM can thus be derived from, and directly related to, these areas.

Below are some advantages and disadvantages of RCM, besides the advantages already mentioned as part of the general PM discussion. [8]

2.2.8.1 Advantages and Disadvantages of RCM

Advantages	Disadvantages
The PM workload is reduced (inspection and replacement)	Setting up RCM is a long and difficult process
By focusing on the primary failure modes, staffing levels are reduced compared to PM, from maintenance employees to the administration of the PM system	The benefits of RCM are not immediate but long-term
The effects of staff turnover are reduced, as the exact procedure has been captured through the RCM analysis and can be used for effective training	RCM requires skilled/trained employees at all levels
Improves the co-operation between different levels of the organisation [8] [9]	The database takes time and continuous effort to set up and maintain [17]

Table 6 Advantages and disadvantages of RCM

2.2.9 Total Productive Maintenance TPM

Similar to RCM, TPM is an expansion and add-on to a basic PM system. It is a strategy that focuses on involving operators in basic aspects of maintenance. It emphasises that operators need to take ownership of and responsibility for the equipment that they operate. They are expected to perform routine maintenance tasks during the normal operation of their equipment. TPM, as a strategy, does not require operators to take over from maintenance staff, but strives to get operators and maintenance staff to work together. [15] [17] [9]

TPM is a strategy that aims to combine conventional PM practices with the total involvement of the employee. TPM focuses specifically on the role of the operator instead of the maintenance personnel. It has five specific aims:

- To establish a company structure that will maximise production system effectiveness
- To setup a practical shop floor system that aims to prevent any losses
- To involve all departments including the support services divisions
- To involve every single employee from senior management
- To achieve zero losses through small group activities

To achieve this, TPM is based on five pillars or core principles that where developed by Seiici Nakajima in Japan. [**15**] In order to implement these pillars, a three-phase plan was developed based on three cycles. Together, they form the nine-step TPM improvement plan. Not each pillar is addressed within each cycle. The combination of which pillar forms part of which cycle is shown in the table below. The five pillars, the cycles and the TPM improvement plan are discussed in greater detail in later sections.

	Measurement cycle	Condition cycle	Problem prevention cycle
1. Continuous Improvement in OEE	✔	-	✔
2. Maintainer asset care	✔	✔	-
3. Operator asset care	✔	✔	✔
4. Continuous skill improvement	✔	✔	✔
5. Early Equipment Management	✔	-	✔

Table 7 The relationship between the five pillars of TPM and the three cycles of the TPM plan [15]

2.2.9.1 The five pillars of TPM

As has been mentioned in the overview, TPM is based on five pillars or core principles. The five pillars are described as follows:

The **first pillar** is the adoption of improvement activities to increase the Overall Equipment Effectiveness (OEE) by attacking the six big losses. OEE is understood as a measure of improvement, which is defined by the following formula: [**15**]

$$\text{OEE} = \text{availability} * \text{performance rate} * \text{quality rate} \quad (1)$$

This formula is calculated for each specific piece of equipment, where availability, performance and quality rate are defined as follows:

$$\text{Availability} \quad = \frac{Total\ available\ time - actual\ down\ time}{Total\ available\ time} * 100\% \quad (2)$$

$$\text{Performance} \quad = operating\ speed\ rate * operating\ rate$$
$$= \frac{Ideal\ cycle\ time}{Actual\ cycle\ time} * \frac{Actual\ cycle\ time * output}{operating\ time} * 100\% \quad (3)$$

For the performance calculation, ideal cycle time is the cycle time that the machine was designed to achieve at 100%. Output is defined as the total output including defects. The operating time is the total available time minus unplanned stoppages. [**15**]

$$\text{Quality} = \frac{Total\ output - number\ of\ defects}{total\ output} * 100\% \qquad (4)$$

The six big losses are defined as:

- Breakdowns and unplanned shutdowns
- Excessive set-ups, changeovers and adjustments
- Idling and minor stoppages (where stoppages are not breakdowns)
- Running at reduced speed
- Start-up losses
- Quality defects, scrap and rework

The **second pillar** is the improvement of existing TDM and PdM maintenance systems, specifically focusing on improvements for the maintenance department. This pillar is also known as maintainer assets care. The implementation of this pillar occurs within the first two implementation cycles and is dealt with in steps 4 to 7 of the TPM improvement plan. This is discussed in greater detail in section 2.2.9.3

The **third pillar** is much like the second, but it aims to establish a level of self-maintenance and cleaning, which are carried out by highly trained operators. It is also known as operator asset care. It forms part of all three cycles within the improvement plan. [**15**] The third pillar has seven specific steps, which are:

- Initial cleaning
- Countermeasure at the source of any problem
- Establishment and implementation of cleaning and lubrication standards
- General inspection
- Autonomous inspection
- Organisation and tidiness and finally
- Full autonomous maintenance

The **fourth pillar** is known as the continuous skill development pillar, where the skills and the motivation of the operators and engineers are improved by individual and group development.

In essence, it is the establishment of a total training programme with continuous training. As with the third pillar this forms part of all three cycles. [**15**]

The **fifth** and final pillar focuses on early equipment management. It focuses on ensuring that the right equipment is procured for the right task, followed by the correct training of both operators and maintainers and a full life cycle plan for each piece of equipment. This is incorporated in steps 8 and 9 of the TPM improvement plan (2.2.9.3).

2.2.9.2 The three cycles/phases of TPM

The cycles are:

- The measurement cycle,
- The condition cycle and
- The problem prevention cycle

The measurement cycle involves steps to determine the AS-IS state of physical assets in an organisation. The current effectiveness of the equipment is established in order to set up a baseline, which is then used throughout the programme to measure improvement.

Within the condition cycle, the present condition of the equipment is established and areas of improvement are identified for future asset care.

The final cycle, the problem prevention cycle, is the roadmap to move equipment effectiveness from its current state to a "world-class" standard. [**15**]

2.2.9.3 The TPM improvement plan

The figure below illustrates the TPM improvement plan and indicates which steps form part of each cycle. A key factor within this plan is the inclusion of the feedback loop that allows the TPM to grow and remain current within the organisation. Below the figure each step is briefly explained.

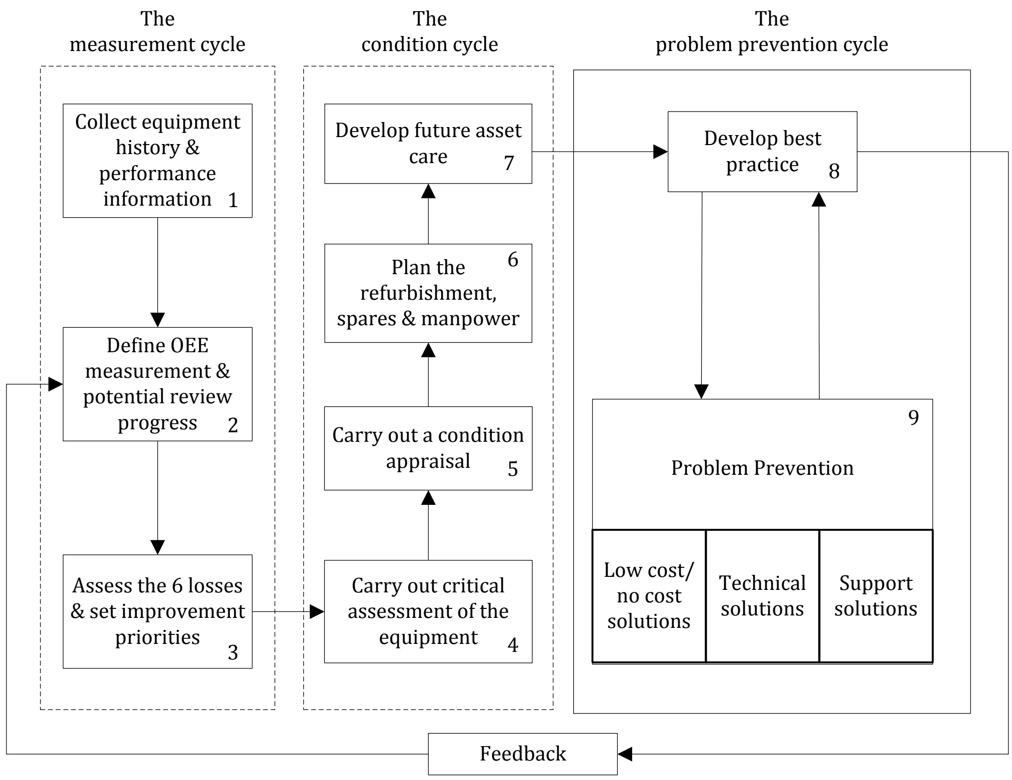

Figure 7 The TPM improvement plan [15]

Within the measurement cycle there are three steps. The **first step** involves the collection of equipment history and performance records. The following three areas are of particular interest:

- Data on equipment performance, availability and quality
- Any records that contain information about problems and breakdowns
- Gauge measurements of noise, pressure, vibration and temperature

The **second step** involves calculating the OEE, defining relevant measurements for each piece of equipment, as well as the review progress based on information from the feedback loop.

Step three involves assessing the six big losses, which have already been defined in the explanation of the first pillar of TPM. A grading scale is employed using 4 levels against which the equipment is compared. This also implicitly sets the targets in these six areas, with each striving to achieve level 4. [**15**]

This concludes the measurement cycle. At this stage, a very clear picture of the current conditions and procedures should have emerged. This picture will form the basis for improvement.

The second cycle is the condition cycle. This cycle includes four steps (4-7) and builds on the first cycle.

The **fourth step** involves critical assessment, where each piece of equipment is assessed in the following areas: safety, availability, performance, quality, reliability, maintainability, environment and cost. For each of these areas a score between 1 and 3 is awarded. The score is based on how large an impact each piece of equipment has on the entire process. This helps to establish the relative importance of each piece of equipment within the process. [**15**]
The critical assessment has the following main outputs:

- Initiates team work between operators and maintainers
- Results in improved understanding of equipment
- Provides a checklist that can be used for the condition appraisal
- Provides emphasis for future asset care
- It also highlights some of the weaknesses regarding operability, reliability and maintainability

Step five comprises the condition appraisal. It uses the same elements as the critical assessment to set up the refurbishment programme that will restore equipment to maximum effectiveness. To do this, each piece of equipment is graphically broken down into sub-assemblies, even individual parts if necessary. Each sub-assembly is then graded as satisfactory, broken down, as needing attention now or needing attention later. [**15**]

The next step, **step six**, follows logically from the previous, as it is the refurbishment step. Refurbishment is carried out based on the condition and the criticality of each item. Within the refurbishment step the following should be included:

- Dates and timescales
- Resource allocation
- Cost estimates
- Responsibility assignment
- Control and feedback

The final step in the condition cycle is asset care (**step seven**). Asset care focuses on establishing an asset care program in which the following three aspects are established:

- Cleaning and inspecting routines

- Checking and condition monitoring methods and routines
- PM plan and service schedules

In order to achieve this, the following needs to be developed in tandem. For each aspect from which tasks have been developed improvements need to be constantly developed to make each task easier. Secondly, visual techniques need to be developed, in order to make each task obvious. Thirdly, training is required so that consistency exists between each shift.

The final cycle is the problem prevention cycle, which contains the final two steps. The **eighth step** involves developing best practices. Best practices are achieved through three interdependent factors. The three factors are: standard operating procedures, best techniques of asset care, and the right tools, spares, facilities and equipment. [**15**] This relationship is illustrated in figure 8. These three factors are held together and rely on training, communication, correct application and consistent application. In figure 8, the four sides of the square represent the four features that overlap and link the three factors.

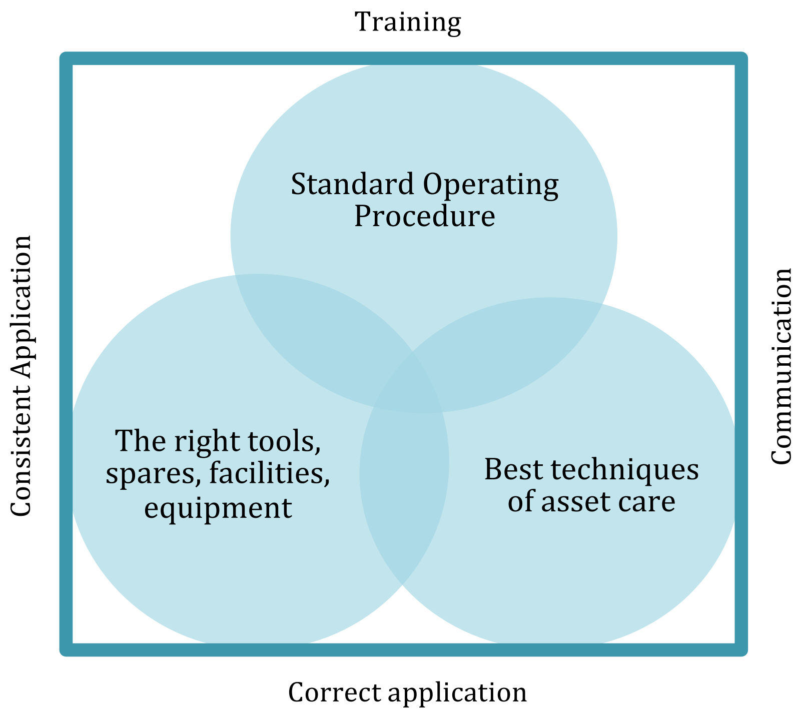

Figure 8 The relationship between the three interdependent factors and the four features that bring them together [15]

Step nine is the final step in the TPM improvement plan and also one of the most important. It entails training and coaching both the operators and maintenance staff in the skill of problem solving. Being able to solve problems will ensure that the TPM programme does not stagnate. It involves many techniques, but the primary two are the 5-whys and the Plan-Do-Check-Act (PDCA) cycle. The 5-whys involve asking why at least five times to establish the root cause of any fault or problem. [**15**]

2.2.9.4 Advantages and Disadvantages of TPM

Advantages	Disadvantages
Maintenance personnel are free to perform complex repair and maintenance tasks and not spend their time permanently inspecting. The maintenance staff can thus be reduced	TPM is not a stand-alone strategy but is rather an add-on or an expansion of a PM or PdM system. Its success depends on the success of the overall PM or PdM system
Operators will operate their machines with greater respect, increasing the life of the equipment and its parts	It inherently has the same advantages and disadvantages that the parent maintenance system has
Equipment can perform optimally	Operators require extra and continuous training (extra cost)
Equipment failure or breakdowns can be minimized	It is more difficult to implement effectively when multiple operators use the same equipment
Operator motivation is increased, which leads to improvement across all aspects from operation, to quality, to equipment life	It requires a shift in attitude for the sense of ownership and the responsibility mind-set that is needed
In the long-term, equipment upgrading and redesign can be better suited to the operator and increase all the above advantages further	It requires strong co-operation between maintenance personnel and operators (both an advantage and a disadvantage
	It is a continuous process that requires continuous input from all parties to be sustainable. Thus, if TPM is properly followed through, in the long term the improvements will also continue to increase, but if personnel is changed, TPM might lose focus and drive

Table 8 The advantages and disadvantages of Lean Maintenance [15] [16]

2.2.10 Lean Maintenance

Lean Maintenance is a by-product of lean manufacturing. Lean, as a concept, became associated with manufacturing and was developed by a research group at MIT. The principles are based on research into the Toyota production system. A summary of the Lean process and concepts are provided below, which, when compared to TPM, will highlight the similarities. [**16**]

The Lean program consists of six phases, with phases 3, 4 and 5 being identical, except for their application area. [**16**]

Phase one is the where the detailed Plan of Action (POA) is developed along with milestones, or sub-targets. During this phase, the project leader and project team are selected and, together with management, draw up a plan.

During **phase two** (the Lean Education phase), the team that is to carry out the project is trained in the Lean process. The Lean process consists of nine elements that are listed below:

- 5-S Process
    - Sort (remove unnecessary items)
    - Straighten (organize)
    - Scrub (clean everything)
    - Standardise (standard routine to sort, straighten and scrub)
    - Spread (expand the process to other areas)
- Identify and Eliminate the Seven Deadly Wastes
    - Overproduction
    - Waiting
    - Transportation
    - Processing
    - Inventory
    - Motion
    - Defects
- Standardised Work Flow (TAKT [cycle] Time, work sequence and Work In Progress [WIP])
- Value Stream Mapping/Process Mapping (use of symbols to draw a map of the steps in a process - Process Mapping)
- Kanban (Visual Cues or Signals to work in combination with JIT)
- Jidoka (Perfection [Quality] at the Source - quality built in, not inspected in)
- Poka Yoke (Mistake or Error Proofing)
- Use of JIT and Pull (Supplying items Just-in-Time [JIT]) and Pulling items only as needed)
- Shewhart Cycle - Plan Do Check Act (PDCA) [**16**]

Phase three (Lean pilot project). This is usually in an area that has the potential for greatest improvement. It has two main functions, i.e. it allows the project team to test the Lean POA and adjust it where necessary, and also serves as an example of what Lean can achieve and thus, motivates the rest of the organisation.

The **fourth phase (Lean mobilisation)** involves expanding the Lean program from the pilot to the entire maintenance department, using the same nine elements. [**16**]

Phase five (Lean expansion) is a continuation of phase four from the maintenance department to all the support services within the organisation, and then the entire organisation. [**16**]

The last **phase (six)** is the **Lean sustainment phase,** where the focus is on continuous improvement to make the business increasingly lean and to allow it to evolve.

From the above phases it becomes apparent how interlinked Lean is with TPM and how dependent Lean is on a TPM/RCM foundation.

2.2.11 Summary of RCM, TPM and Lean

This short section is a summary of three of the current best practices in PAM and also illustrates how they relate to each other and fit together.

RCM is a PAM strategy that focuses on determining **which** maintenance to do **when**. It is a strategy that selects the most efficient and effective maintenance task based on the requirements of the system, component or part. [**16**] [**8**]

TPM focuses on **how** to best to perform these tasks, by emphasising the role of the operator and the maintainer in the PAM system. It aims to change the culture within the organisation to strive for efficiency and effectiveness in how each maintenance and operational task is performed. [**15**]

Lean Maintenance builds on these two foundations. It **combines** them and **integrates** TPM and RCM. Lean is the roof that brings them together and it can only exist if both are in place. While both RCM and TPM can exist in isolation, they are improved and strengthened by Lean Maintenance. To illustrate this concept, see figure 9.

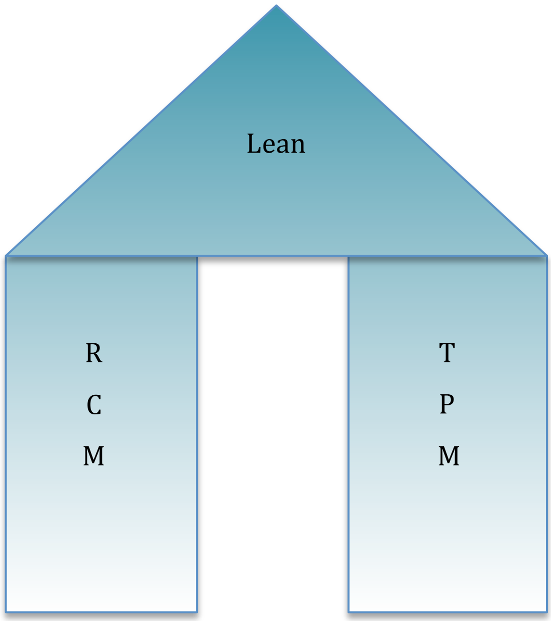

Figure 9 The relationship of Lean Maintenance to RCM and TPM [16]

2.2.12 Standards

Standards provide a standardised form of existing definitions, explanations and requirements that ensure better understanding and allow for communication in a common language in a specific field. In essence, standards ensure that when two parties use the same word, they also mean the same thing and are understood thus. The purpose of standards is to make regulation and compliance easier. Standards are developed by different organisations in different countries. There are a few notable exceptions, such as the International Organisation for Standards (ISO). Two of these standards that are of particular interest are the Publicly Available Specification (PAS) 55 and the International Railway Industry Standard (IRIS). [**18**] [**4**] [**11**]

PAS 55 is a Publicly Available standard that was developed by the British Standards Institute together with corporate partners. It was first published in 2003 and then updated in 2008. It was published in response to the demand from industry for a specific standard for asset management and it focuses on the management of the entire life cycle. The core of PAS 55 is a 28-point checklist. The number of points varies from organisation to organisation, depending on the industry. PAS 55 can be broken down into seven phases, which are:

- General requirements
- Asset management policy
- Asset management strategy, objectives and plans
- Asset management enablers and controls

- Implementation of asset management plans
- Performance assessment and improvement
- Management review

The 28-point checklist forms the details of these seven phases. The 28 headings of the checklist can be found in the table below, along with the corresponding phase.

PAS 55 - 2008	
Phase	Check list heading (and explanation where required)
General requirements	General requirements
Asset management policy	Asset management policy
Asset management strategy, objectives and plans	Asset management strategy
	Asset management objectives
	Asset management plan(s)
	Contingency planning
Asset management enablers and controls	Structure, authority and responsibilities
	Outsourcing of asset management activities
	Training awareness and competence
	Communication, participation and consultation
	Asset management system documentation
	Information management
	Risk management process(es)
	Risk management methodology
	Risk identification and assessment
	Use and maintenance of asset risk information
	Legal and other requirements
	Management of change
Implementation of asset management plan(s)	Life cycle activities
	Tools, facilities and equipment
Performance assessment and improvement	Performance and condition monitoring
	Investigation of asset-related failures, incidents and non-conformities
	Evaluation and compliance
	Audit
	Corrective and preventative action
	Continual improvement
	Records
Management review	Management review

Table 9 The PAS 55 28-point checklist [4]

IRIS is the International Railway Industry Standard that was developed due to the need for European countries to have common standards, in order for trains to be allowed to operate in different European countries without having to stop at borders and transhipping. It is ISO 9001 compliant (ISO 9001 being the quality management system standards) and consists of two sets of core requirements. Furthermore, it is made up of 13 documented procedures and 19 mandated processes. These two lists can be found in appendix B, together with the list of key ISO differences. IRIS is a standard, not just for an entire rail operations organisation, but also for railway equipment manufactures. The largest advantage of this is that due to IRIS, the request for tenders and the tendering process have been streamlined and, if both supplier and operator are IRIS accredited, they share a common language. [**18**]

3 The current state of PAM in Metrorail

3.1 Overview of Metrorail

Metrorail provides almost all of South Africa's passenger rail services, with some notable exceptions [**21**]such as luxury trains and the Gautrain. Metrorail is owned by the Passenger Rail Agency of South Africa (PRASA), which in turn is a wholly State-Owned Enterprise (SOE).

Metrorail operates in four of South Africa's provinces, namely the Eastern Cape, Gauteng, Kwa-Zulu Natal and the Western Cape. These regions operate independently of one another and report to the Metrorail Head Office in Johannesburg. [**22**] Each region has its own maintenance depot and is also responsible for the maintenance of the operational asset base (infrastructure and rolling stock). [**23**]

Metrorail transports about two million passengers per day, thereby accounting for roughly 15% of the people using public transport daily in South Africa. [**24**] They operate at 468 stations (317 owned by PRASA and 151 by Transnet), with the rolling stock fleet consisting of approximately 400 train sets, and with train sets varying in size between 8 and 14 coaches per train set.

3.2 Short overview of Metrorail's maintenance context

Metrorail was originally part of the larger rail organisation called SATS (South African Transport Service), which became Transnet in 1990. [**24**] After being created and later spun off in 1997, it was under the control of many different parent companies, from Transnet to the SARCC (South African Commuter Corporation), which then became PRASA (Passenger Rail Agency of South Africa). [**21**] Each new shift brought change and instability, along with restructuring and different management. During the transfer of Metrorail from Transnet to the SARCC, most of the large rail engineering services were separated from Metrorail and remained with Transnet. [**25**] These services include the wheel shop, where all wheel-related maintenance takes place, the overhaul workshops, where the motor coaches and plain trailers are overhauled, and some other smaller services.

This split has had the net effect that the Metrorail rolling stock maintenance operations involve inspecting train sets, replacing parts and ordering parts. The required parts do not come from the parent company, but rather from outside vendors, which makes Metrorail highly dependent on activities beyond their control. There are, however a few exceptions to this. A specific example is the traction motors, which are serviced and overhauled in-house.

The vendor that Metrorail is most dependent on is Transnet, [**26**] specifically the Transnet subsidiary TRE (Transnet Rail Engineering), who performs most of the general overhaul work and all wheel related maintenance as well. TRE has been the sole supplier of all maintenance relating to wheels in the country for many years. [**27**] Their coach and locomotives services are the largest, and in some cases the only, in the country. This heavy dependence has resulted in many challenges to Metrorail, as illustrated in the following paragraph.

According to the CEO of PRASA [**28**], when the SARCC became PRASA and ownership and operation of Metrorail was completely transferred to PRASA, PRASA found itself in a financially difficult situation. This was exasperated by the 25% and 32% increases in electricity in 2008 and 2009. [**28**] In order to remain in operation, a cost containment exercise was implemented in July 2009, with various facets and numerous intended outcomes. One of these unanticipated results was that for nine months payments for wheel maintenance were not made to TRE and thus, no maintenance was done. [**25**] This caused Metrorail to use up their float of wheels and has resulted in a growing backlog that still existed in October 2011. [**29**] The result was that some train sets have had to be shortened and in some cases fewer scheduled trains. The wheel situation is discussed in greater detail in chapter 6.2.1.

The second effect of the cost containment exercise was that under-staffing rose up to 40%. Currently about 40% of positions within Metrorail are vacant. [**30**] The hardest hit by this shortage of positions are the support services, such as HR, Finance, Procurement, etc. This has led to exasperation and tension [**31**] between the frontline (operations and maintenance) and other support services, with the support services unable to support the frontline effectively and efficiently.

The final element of this context is that in the last few years, centralisation has taken place in order to improve economies of scale, with the regions losing autonomy. [**3**] An undesired side-effect is that the level of bureaucracy has increased, which causes each region to be less agile when any changes are required. Although the issue of decentralisation and centralisation is of critical importance, it does not form part of the scope of this thesis.

3.3 Current procedure

At present, there exists no concrete, overarching maintenance policy within Metrorail or PRASA. Maintenance is being done based on the requirements of the Railway Safety Regulator (RSR) or "how it has always been done" (Dr Daniel Mtimkulo, Executive Manager of Engineering 2011, oral communication, 7 October).

This manifests itself in two primary forms of maintenance, namely time directed maintenance (TDM) or Run-To-Failure (RTF), according to the senior engineers from Metrorail. [**25**] [**3**] However it is unclear what percentage of these RTF's are actually unplanned failures that are then resolved versus failures that are purposefully allowed to occur. This is an important distinction, which is discussed in greater detail in section 2.2.4. Currently, there is movement within the Metrorail Engineering Services Department to move from primarily TDM to Condition directed Maintenance / Predictive Maintenance (PdM). No programme has been developed as yet. [**3**]

The current TDM cycle is based on the average number of kilometres travelled, which are then converted into days. This average was calculated based on the kilometres covered and the passenger numbers from pre-1998 [**10**]. The maintenance cycle was further divided as per the region. In the Western Cape, for example, there are three regions: North, Central and South. Splitting each area into these three regions is only feasible if the train sets that operate in these regions operate exclusively within each region. Should the train sets change region, their operational characteristics would no longer match the pre-determined maintenance cycle. Similarly, if the coaches within the train set are exchanged, they would fall into the scheduled maintenance cycle (shedding cycle) of the existing train-set. [**32**]

The current schedule for TDM has three cycles, namely a 2-week, a 4-week and an 8-week cycle. These cycles are known as Passenger Safety and Comfort (PS&C), Intermediate Shed, and a Full Shed respectively. This means that every train-set should ordinarily come into the maintenance depot for an inspection every two weeks, where every fourth week includes the Intermediate Shedding activities and every eighth week the Full Shedding activities. This cycle was determined in 1998, based on the main agreement between the SARCC and Metrorail [**10**]. It was calculated based on operating conditions and procedures, as well as equipment condition prior to 1998. According to senior personnel in Metrorail, they require a more flexible, simple and applicable system. [**3**]

All the maintenance procedures and strategies that are currently in use are based on the manuals and information from the Original Equipment Manufacturers (OEM). According to Moving South Africa [**33**], a research group from the Department of Transport, the average age of the commuter rail fleet in 1999 was 25 years, with no new coaches having been bought since the mid 1980s. It has been more than 25 years since new coaches where bought by South Africa. Thus, the maintenance strategies that are based on OEM specifications are still in use today. [**10**] PAM has come a long way since the 1980s; however, Metrorail and PRASA have not kept up with the advances in technology and strategy. [**3**] Further details of the strategy and exact tasks that are performed in each shedding cycle are discussed in section 6.3.

3.4 The current PAM policy

Currently, the PAM system at Metrorail is loosely based on the following three facets:
Firstly, and predominantly, maintenance at Metrorail has seen little change in the last two decades. The premise of this statement is that the current scheduled maintenance cycle, along with the Time Directed Maintenance (TDM) activities are based on the SARCC-Metrorail main agreement from 1998, which was compiled after Metrorail and its assets where transferred from Transnet to the South African Rail Commuter Corporation (SARCC). At this stage, Metrorail had no Computerised Maintenance Management System (CMMS), which meant that all records and procedures where paper-based. [**22**] To simplify, maintenance management and the maintenance cycle were based on the average kilometres travelled per train set, which in itself was correlated to the level of wear and tear and actual maintenance requirements. This has already been discussed in greater detail in section 3.3.
The second predominant PAM strategy was Run-To-Failure (RTF). In essence, any component or system that did not deteriorate along a predictable and accepted path, or one that failed after a period of time, or those components whose rate of deterioration could not be measured, were addressed using RTF. [**23**] Due to the technology that was available in South Africa at the time, the condition of only a minority of systems and components could be measured and their failure predicted. These RTF were not selected because they where insignificant or the most financially feasible, but in most cases, because there was no other choice.

However, as has been mentioned in section 3.2, in the past decade the operating conditions of Metrorail have changed, yet the maintenance cycle has stayed the same. This lack of adaptation to the current situation has resulted in the second aspect that governs the way maintenance is performed, i.e. reactive maintenance. As was discussed in section 2.2.4, the key difference between RTF and CM/BM is that after analysing all possible alternatives, the best strategy is RTF. With CM/BM components or systems that could be maintained according to a different strategy are found to have failed unexpectedly. [**8**] As discussed in section 3.3, the current split between RTF and CM/BM is unknown; however, the general consensus among the engineers at Metrorail and the author is that the rate of CM/BM is increasing. [**25**] [**34**] This is not solely due to the current scheduled maintenance cycle.

The last and most recent aspect that influences the current PAM strategy at Metrorail is the Railway Safety Regulator of South Africa (henceforth referred to as the Regulator) [**35**]. The Regulator was established after the National Railway Safety Regulator Act, 2002 (Act No. 16 of 2002). The primary focus of the Regulator is the safety of the employees, the passengers and the public. In order to be allowed to operate, Metrorail needs to adhere to the rules and regulations set out by the Regulator. The act of balancing the requirements of the Regulator with the requirements of PRASA and, by implication, the government is challenging. A close relationship between Metrorail and the Regulator needs to exist in order for Metrorail to remain safe. Furthermore, the safety standards set by the Regulator need to be reasonable and do not cause Metrorail operations to become unviable.

These three aspects form the basis of the current PAM of Metrorail. The author has learnt that the existence of a PAM system does not guarantee the existence of a formal policy as defined in section 2.1.1

3.5 Shortcomings of the current system

Some of the shortcomings of the current system are immediately evident. First, the two-week interval for scheduled maintenance is still based on pre-1998 operating conditions. Since then, the passenger numbers have increased, the schedule has changed and, in some cases, the lines as well as the station locations and number of stations have been changed. The demand for rail travel is so high that all available capacity is being utilized every day. Initially, taking the Western Cape as an example again, the original procedure included having six train sets on reserve that could be used as substitutes, should any scheduled train pick up a serious fault [**10**]. At present, the availability of plain trailers and motor coaches is so low that train sets have had to be shortened and the number of scheduled train trips decreased.

Second, due to current low availability, train sets are no longer operating exclusively within their predefined region. [**32**] This means that the wear rate and wear characteristics of the train set do not match the scheduled maintenance plan. Alternately, if the change is taken into consideration, the planning schedule needs to be constantly adapted. This results in an uneven workload at the workshops. In some cases, this fluctuation has led to train sets not being available on schedule. This causes more rescheduling and train sets being moved between regions to make up the shortfall. [**36**]

Furthermore, in order to keep the maximum number of train sets running, in some cases the train sets are being broken up. [**32**] The coaches that are in need of maintenance, or that did not receive the required maintenance on time, are removed from the train set. Other coaches that are operational then replace these coaches. These ‘new’ coaches, however, are then at a different phase within the 2, 4, or 8 week shedding cycle. This results in over or under-maintenance, with the former being very costly and the latter resulting in increased faults and breakdowns.

The challenging state of the current operational norm has been affected by the lack of available spare parts, the most chronic of these being an acute shortage of wheel sets. The wheel set problem is discussed in greater detail in section 6.2.1.

The current maintenance strategies are based on knowledge and understanding of PAM from before the 1980s [**10**]. Thus, the current state of maintenance is neither as effective as it should be nor as efficient as it could be.

4 RAM - a Proposed Policy

4.1 The Proposed PAM Policy

The following is a recommended policy statement. It was developed by the author and based on knowledge gained from extensive literature study and an investigation into PAM and different best practice strategies. The remainder of this thesis sets out to validate the statement.

Implement a suitable, sustainable and living national maintenance programme based on the requirements of the asset component, the system and the organisation. This policy will also be known as Requirement-based Asset Management (RAM).

The components of this statement are now discussed.

The basis for RAM is that the PAM system needs to be centred on the needs of the asset as well as the needs of the organisation. The higher-level understanding of the organisation's needs is not always easily translated into quantifiable standards and procedures that can be measured and thus controlled. A common engineering principle states that if you cannot measure it, you cannot manage it (based on a statement by Lord Kelvin) [**37**]. A policy in itself does not have clearly measurable outcomes or goals and if it does, they are normally only in relative and not absolute terms. A policy, however, leads to a strategy, where each procedure in the strategy does have measurable outcome. [**14**] That is why much more research, time, effort and money are being spent on maintenance strategies instead of specific policies. [**19**] In order to investigate the validity of this policy, a strategy needs to be derived from it, which can then be evaluated and, based on that evaluation, conclusions may be drawn regarding the policy.

4.2 RAM unpacked

In this sub-section, the policy statement will first be discussed and explained in general terms. To understand the policy more clearly, each of the terms will be defined and explained:

Implement: To carry out or do, as opposed to merely investigating. The PAM system that is developed based on this policy needs to be put into action. By implication this also means it needs to be possible. The PAM system requires a concrete action plan. [**38**]

Suitable: This is one of the most important words in this policy. It means that any PAM system or strategy derived from this policy needs to be realistic enough to be achievable, yet challenging so as to create a goal to strive for. It also needs to take the current situation of the organisation into consideration. It needs to align with the high-level requirements of the company, its shareholders and, in this case, the relevant Regulator. It also needs to abide by national laws. Including all health and safety laws. [**20**] [**38**]

Sustainable: The PAM system needs to be sustainable from an environmental viewpoint. It also needs to be sustainable in the business sense. The derived system needs to aid the growth and improvement of the company that it is applied to, in such a way that it does not jeopardize the current operations nor the ability of the company to operate in the future. In short, the PAM system needs to be affordable and have a positive ROI. A sustainable PAM system is also both effective and efficient.

Living: This term has been included to highlight the need for improvement, specifically in the ever-evolving field of PAM. Thus, any system that is derived from the policy needs to be adaptable. It must evolve with the needs of the company, and also to the change and opportunity presented by new or improved PAM strategies and technologies. This is because a current strategy or method might no longer be the most suitable in a few years time. It also needs to consider the life and age of the asset when choosing the most suitable replacement and maintenance strategies [**8**]

National: In large organisations with multiple branches, the organisational structure and Regulatory requirements do not make it feasible to have different strategies in different regions. The application of each strategy will lead to differing requirements in different regions, while the strategies themselves need to remain standardised. These strategies thus also need to be flexible enough to allow for differing conditions in each of the country's regions. This means that the policy needs to be broad enough to allow for regional variation when needed. [**38**] The policy also needs to take the suppliers and partners of the organisation into consideration and be communicated to them, so that both are aligned.

Programme: A programme is a system or combination of methods and strategies that are applied in a particular area. The PAM system cannot be limited to one particular form of maintenance. Different failure modes require different preventative maintenance techniques. Thus, all strategies that are considered need to form part of an organised, structured system, for manageability, effectiveness and efficiency. The different failure modes are discussed in greater detail in the Reliability-Centred Maintenance section (2.2.8). [**38**] [**15**]

Requirements: The requirements for any asset component or system depend on the different failure modes of each component or system and the expected performance thereof. Although standardisation has its advantages, specific failure modes can only be addressed by using a specific set of concepts.

The second facet that is covered in requirements is the regulations, as per national laws and applied through the Regulator. In many elements of an organisation, national law requires a specific maintenance action. This is particularly relevant when considering health, safety and environmental aspects. These cannot be ignored, even if a more suitable alternative exits. For this policy, the emphasis of requirement is placed on understanding different dimensions of PAM at various levels. These levels range all the way from the smallest part, to the needs of the organisation as a whole.

The final facet emphasises the importance of considering the entire organisation. The policy needs to take all the organisational requirements into consideration. These include, but are not limited to, other policies, the strategic intend of the organisation as well as other statutes.

4.3 Shortcomings of a generic policy

An organisational policy is created based on two key elements, as was explained in the literature study (section 2.1.2). The first is the investigation of the specific field to which the policy should apply, the second is the accumulation of understanding and insight into the specific organisation that it will be implemented in. It is therefore very difficult to evaluate any generic policy. In order to do so, the policy needs to be applied within an organisational context and evaluated in that context, based on the deduced strategies and recommendations. General conclusions can then be drawn with regard to the generic policy based on the specific results.

For this thesis the policy will be applied in the organisational context of Metrorail. The next chapters of this thesis will discuss the policy within Metrorail's context in order to establish its validity and suitability. [**11**] [**13**]

4.4 Benchmarking the generic policy

Benchmarking is used to establish the performance of an organisation by comparing a number of measures in similar organisations. Benchmarking can be done from a large scale, such as the whole organisation, to a very small scale, for example specific procedures. Benchmarking was also used as one way to establish the usefulness of RAM as a generic policy.

Benchmarking consists of these primary elements as defined by Anderson [**39**]:

- **Plan:** The development of critical success factors and performance measures.
- **Search:** Find benchmarking partners.
- **Observe:** Document the partners' process', both performance and operational.
- **Analyse:** Identify gaps in the performance and find the root causes for the gaps.
- **Adapt:** Choose "best practice", adapt to the partner's conditions and implement.

These five steps form a cycle that can be repeated in order to incrementally improve the practices of an organisation. Section 4.4.1 discusses the application of these five steps.

4.4.1 Application of benchmarking

(a) Planning: For the benchmarking exercise of the proposed generic policy, the asset management and/or maintenance policies of various organisations were considered. However, as the policy statement is generic, there is no distinct measure that can be used, as different industries require different policies. Limiting the benchmarking to the policies of organisations that are all similar would allow only for a specific comparison and specific conclusions. This would limit the value that can be derived from a benchmarking exercise. In order to draw general conclusions, multiple benchmarking exercises would need to be performed. An alternative would be to consider the general principles and elements that a policy should contain and benchmark the generic policy against these principles.

(b) Search: Initially different rail industry policies were considered:

- Network Rail [**40**] [**41**], the company that is responsible for Brittan's entire rail network.
- Italian Railways [**42**].
- NSW Transport - RailCorp [**43**] [**44**] [**45**], a private Rolling Stock operator in New South Wales, Australia.
- A benchmarking exercise performed on New Zealand's public transport system by the University of Auckland [**46**].

But, as mentioned previously, benchmarking against only one type of industry would result in skewed conclusions. It was thus decided to benchmark the generic policy against the policy requirements as set out by PAS 55 [**4**] [**11**].

(c) Observe: PAS 55 sets out 11 requirements/criteria that make up an asset management policy. They are briefly listed below:

A policy shall:

1. Consistently be based on the organisational strategic plan.
2. Be suitable to the type and size of the organisation's assets and operations.
3. Be coherent with other organisational policies.
4. Be consistent with the overall risk framework of the organisation.
5. Provide a structure within which the asset management strategy, objectives and plans can be produced and implemented.
6. Commit to compliance with legislative, regulatory and statutory requirements as well as any other requirements to which the organisation has bound itself.
7. Clearly state the principles the organisation applies to itself, specifically towards health safety and the environment.
8. Incorporate a responsibility to continual improvement of asset management.
9. Be documented, implemented and maintained.
10. Be communicated clearly throughout the organisation as well as to all relevant stakeholders outside the organisation.
11. To be reviewed periodically for the sake of relevance and consistency with regard to the organisational strategic plan.

(d) Analysis: The overlap between the requirements, as set out by PAS 55, and the generic policy statement are listed below. The item number from PAS 55 is listed first, followed by the relevant terms that are discussed in the generic policy statement.

1. Requirements.
2. Sustainable.
3. Suitable, National.
4. Requirements.
5. Program.
6. Requirements, Suitable.
7. Sustainable, Requirements, Suitable.
8. Living.

9. Implement, Living, Program
10. National
11. Living, Requirements

(e) Adapt/Conclusions: From the analysis it was found that all areas, as prescribed by PAS 55, are covered in the proposed generic policy. However it was noted that there are differences in emphasis. It was concluded that the difference in emphasis arises due to the differing context of PAS 55 and the generic policy statement.

PAS 55 has been developed by the British Standards Institute in partnership with 1st world companies, thus with a 1st world environment in mind. The generic policy statement was developed for the South African environment where the circumstances differ. This differing environment resulted in the difference in emphasis. This is particularly relevant to large parastatal organisations.

5 RAM within the Metrorail context

In section 2.1.2 it was stated that in order to develop a suitable PAM policy, an in-depth knowledge and understanding of the field of maintenance as well as the organisation is required. RAM is a generic policy statement; its suitability to Metrorail therefore needs to be investigated. This investigation forms the basis for this chapter.

5.1 Alignment with high-level requirements

The suitability of the policy to the high-level requirements of Metrorail is discussed in this section. This will be done for the vision, mission and values of both Metrorail and PRASA, as they are very similar and in most cases, interchangeable.

The vision of PRASA is "to be South Africa's number one public transport operator" [**21**]. Although it is difficult to link the RAM to this vision and establish the level of alignment, the fact that there was no policy before means that any policy that focuses on improving the PAM system will help the company achieve its vision. The same is true for the vision of Metrorail, as this vision has to conform to that of PRASA. The details of the legislative mandate of both PRASA and Metrorail can be found in Appendix C.

The missions of both PRASA and Metrorail are identical in that both include striving for sustainable transport solutions in the same three key areas. These are service excellence, innovation and modal integration [**24**]. In the following paragraphs these three areas are discussed along with how the policy fits in with them.

Service excellence - is defined by both PRASA and Metrorail as superior performance that is safe, reliable and affordable. It also needs to actively build brand loyalty. The safety and reliability are the reasons why maintenance is performed and the policy provides concurrent guidance in this matter. The policy is also in line with the affordability requirement, as it does not advocate the most expensive strategies and systems, but rather a suitable PAM system. [**21**] [**24**]

Sustainability - has already been set out in the policy, and thus the policy would steer any PAM strategy and system of Metrorail in that direction.

Modal Integration- The policy is broad enough to be applicable not only to the Metrorail operations, but also to the other operations of PRASA. Part of the understanding of this term is that both Metrorail and PRASA want to increase the level of innovation. The policy accommodates this, as it requires the strategies and programs used, to be living and therefore evolutionary and innovative. [**21**] [**24**]

The values of PRASA and thus Metrorail are more difficult to relate directly to the policy. However, when developing the PAM system, these values must be taken into consideration. The policy does make allowance for the values to be incorporated into the strategies used within the PAM system, once again by requiring that the strategy and, by extension, the system, to be suitable. If the PAM system and strategies hinder the application of these values within the company, then they are not suitable and so go against the policy.

In order to test and validate the policy further, a proposed maintenance strategy is derived and then applied in three different areas of Metrorail. These three areas are discussed in section 6. The proposed strategies, as well as the three case studies, each form their own chapter in this thesis.

The three areas chosen to validate the policy were chosen specifically because of their different roles and the different levels at which they are found within the organisation. The specific details and the reasons for the choices of case studies are explained within each case study. Mission Directed Work teams (MDW®) [**47**] does not form part of the formal validation, but will be briefly discussed (5.3.2) to show some of the progress that has been made at Metrorail.

5.2 Metrorail RAM Roadmap

5.2.1 High-level derivative of RAM

Before looking into the roadmap specifically, some general observations are required. These are called high-level derivatives of RAM and are discussed in the following two paragraphs.

The first and most important derivative is that there is no one strategy or procedure that is sufficient to satisfy all the requirements of a PAM system. As was discussed in the literature (2.2.3), every PM strategy is made up of four elements: TDM, PdM, FF, RTF and possibly DOM as a fifth, although sources differ on whether to include or exclude it. No current best practice strategy is based only on one of these. The two predominant current strategies (TPM and RCM) both include all elements mentioned. The first derivative is thus that any strategy that is implemented needs to be a hybrid strategy.

Secondly, within any proposed strategy, consideration needs to be given to taking the AS-IS situation into account. Lean Maintenance, according to Smith [**16**], is the current world class standard. As was mentioned before (section 2.2.10), Lean is an improvement of TPM. Thus, if TPM, as a maintenance strategy and program, is not successfully in place, Lean Maintenance cannot be implemented. [**16**] Based on the current state of maintenance at Metrorail, RCM and TPM should form the basis of any PAM improvement program. RCM and TPM, as recommended strategies, are discussed in greater detail in section 5.2.3.

Section 5.2.2 covers the development and application of the generic policy-based roadmap as it could be applied in Metrorail. First, the basic outline of the roadmap is explained, followed by a more detailed explanation of each element. For the purpose of validation, elements of this roadmap are then applied to specific areas. The discussion of the selection of each area and application of the roadmap in these areas are discussed in chapters 6, 6.1, 6.2 and 6.3 respectively.

5.2.2 Basic Roadmap outline

This roadmap has been developed based on the current state of PAM at Metrorail, as described in section 3. A two-phase approach is suggested.

Phase 1 entails applying RCM to the Rolling Stock and Infrastructure departments of Metrorail, but subdivided within each geographical region. The implementation of a TPM or TPM equivalent program should occur in parallel with the RCM application at the workshops, in the case of Rolling Stock, for the infrastructure work teams, as well as operations. The initial implementation should be followed closely by an organisation wide rollout. Once TPM is firmly in place, Lean Maintenance should be applied to integrate and consolidate the RCM and TPM programs.

Phase 2 involves implementation and accreditation of either PAS 55 or IRIS or both, depending on the prerequisites of the standards and the suitability of each to the organisational and PAM situation at Metrorail at that time.

5.2.3 Why RCM and TPM?

As was discussed in the literature study, RCM and TPM are the core building blocks of most current successful living PAM programs, as understood from section 4.2. Both adopt an attitude of hybridisation towards PM strategies and procedures, and both incorporate structured implementation plans that tackle PAM in the context of the entire organisation, not only the operations and maintenance departments in isolation. RCM and TPM both allow for further development of the PAM system. [**16**]

Both RCM and TPM are firmly rooted in statistical foundations and, according to Smith [**8**], common sense. This element of common sense makes them easier to understand and easier to implement in an organisation where a PAM policy has not existed and the PAM strategies are stagnant. It allows for faster uptake and understanding throughout the organisation, which is particularly important for TPM, as it is dependent on complete employee involvement. [**15**] [**8**]

As has been repeatedly stated, Lean Maintenance is not a suitable maintenance strategy until a foundation of TPM is in place. [**16**] However, once this foundation is in place, Lean is the logical next step, specifically when considered in a context where RCM has been applied to the Rolling Stock and the Infrastructure departments.

TPM at Metrorail: At the time of writing this thesis, a form of TPM implementation had already been launched throughout the organisation. This implementation is a testament to TPM and its perceived value at Metrorail. A short discussion of the implementation of the TPM-like program forms its own sub-section (5.3.2).

RCM in Metrorail: Due to the time constraints of this project, the investigation of implementing RCM was restricted to the Rolling Stock department in the Western Cape region. The RCM application at Rolling Stock is documented in chapter 6.2.

5.2.4 Why IRIS and PAS 55?

The recommendation of IRIS and/or PAS 55 in particular, is based on the overview of these two standards according to the literature study (section 2.2.12). Both standards are understood to be superior in their respective fields and so should be seen as viable targets to strive towards. [**18**] However, as they would not form part of phase 1, but only be incorporated in phase 2, a full study should be conducted closer to the time in order to make the most appropriate choice.

IRIS and PAS 55 are referred to, because of their logical link to the operations at Metrorail. The majority of the actions that Metrorail perform are asset management related, hence the applicability of PAS 55. Metrorail operates within the rail industry and has already achieved ISO certification. IRIS supersedes ISO, in that any IRIS accreditation/audit automatically includes ISO. IRIS is also the largest international standard specifically developed for the rail industry and is widely used, specifically in China and Europe. This is of significance as future recapitalisation programs will likely lead to co-operation with Europe and/or China. [**4**] [**11**]

Both these standards, as well as other standards that could be applicable, require further investigation to establish the following:

- The suitability of each standard to Metrorail
- The benefits it would have
- The potential ROI
- When it should be implemented
- How it should be rolled out
- The potential long-term impact

5.3 Phase 1 unpacked within the Metrorail context

In this section, the expected impact of applying phase 1 to Metrorail is expanded on. Emphasis is placed on areas that are of significant value to Metrorail. The areas of interest are:

- The Policy Break-down Structure (PBS)
- Mission-Directed Work teams (MDW ®) [**47**]
- Asset management of the maintenance equipment
- Recapitalisation
- Human Resource Management and training
- "Make or buy "decisions
- Standards and standardisation
- The top and bottom of the organisation
- Special cases

5.3.1 Policy Break-down Structure

Part of the full RAM-guided strategy is the design and implementation of the Policy Breakdown Structure (PBS). A PBS takes the policy and applies it to the strategies, which are then broken down into procedures and other smaller packages, before the PBS cascades those procedures and packages down to ground level. At ground level, these work packages and procedures are translated into workable and measurable targets and Standard Operating Procedures (SOP). This is a simple explanation for a complex, long-term task. The concept of a PBS is new and is documented for the first time in this thesis. [**48**]

A complete PBS on all physical assets would entail a significant amount of work. To reduce the workload and maximise the impact, RCM principles should be used to identify the specific failure modes that are associated with retaining the functionality of the system. One would thus start by performing a Pareto analysis and considering the areas that cause 80% of the breakdowns/unscheduled downtime. [**9**] [**17**] [**8**] Subsequently, the next largest causes of service interruption would be considered, followed by the rest of the causes in descending order of impact.

In a similar trend, supervisors and management need to align their focus on these problem areas and support the frontline. Through the TPM side of the RAM-based strategies, SOP that present problems would then be highlighted and brought to senior attention more rapidly than before. This would occur when a MDW® (see 5.3.2) team realises that a procedure is presenting a problem and elevates it through the Team Leader, Coach, Master Coach etc. to the appropriate level. [**47**] This line of communication would also work both ways. Thus, new or revised SOP would reach the shop floor much faster and be implemented efficiently. The new SOP would be developed and derived from the implementation of RCM on the rolling stock and the infrastructure.

Over time the PBS would overhaul/update the existing SOP and in cases where there are none, SOP would be created. The PBS could also validate existing SOP and give the employees, from the frontline to the engineers, confidence in the SOP. A crucial part of RAM, or any PAM policy, is a review and audit procedure that keeps the PBS current and applicable.

The development of the PBS does not fall within the scope of this thesis, but should be one of the next steps carried out within Metrorail. A full recommendation of the further work can be found in chapter 7.

5.3.2 Mission-Directed Work Teams

Part of the TPM aspect of the RAM-guided roadmap is the implementation of MDW®, [**47**] which is being spearheaded by the PRASA Rail Chair for Maintenance Management. The basic principles behind MDW® are TPM-based and the aim is to give the frontline a clear understanding of how they- and their work- fit into the organisation as a whole. This is meant to help them establish what their goals and targets are. Initially, MDW® was only implemented at Rolling Stock and Infrastructure departments in all the regions, but this quickly spread and MDW® is being implemented across the support services, including Head Office. It will help inter-departmental relations and cooperation between teams from different departments. It will also allow the process of fault-finding and failure analysis (part of the RCM program) to be streamlined.

The entire MDW® program consists of eleven modules, where the latter modules are based on Lean Manufacturing/Maintenance principles. The eleven modules are:

- Mini-Business Goal Alignment
- Problem Solving Tool-kit
- Visual Workspace 5S
- Asset Care
- Engaging Leadership
- Lean Workflow
- Coaching for Performance
- Quality Assurance
- Value Driven Service
- Process Improvement 7W
- Self-Development

A key success factor for the MDW® program is whether or not senior management understands and embraces it. Involvement by senior management will result in improved inter-level cooperation. [**47**]

5.3.3 Asset management of maintenance equipment

TPM, through MDW®, will improve asset care by improving basic PM activities that are carried out by the operator. [**15**] [**47**] This will be achieved by instilling a greater sense of ownership and thus a sense of responsibility for the care of the equipment. The basics of PM expected from operators will be: inspecting, cleaning, lubricating and operability testing. Once the first half of phase one is complete, Lean Maintenance can be implemented by applying RCM to the workshops and mobile work trucks. In conjunction with operator maintenance, Lean Maintenance will result in longer equipment life and better equipment performance. Lean will also generate a basis for a replacement policy of maintenance equipment as well as improvement programmes for existing equipment based on RCM principles. [**16**] [**8**]

Due to operator maintenance, operators will gain a deeper understanding of their equipment, which will result in better feedback regarding the suitability of current equipment for the task, as well as suitable input with regards to new equipment. This will also create an improved sense of worth and contribution amongst frontline employees. [**47**]

Another aspect that will be investigated through TPM and then Lean Maintenance is the maintenance equipment requirements for the Rolling Stock Recapitalisation Program of 2015, focusing on equipment integration between the current equipment and the equipment required for the new vehicles. [**28**]

5.3.4 Recapitalisation

The new Recapitalisation Program needs to consider maintainability and total life cycle cost. [**17**] [**9**]
Due to its RCM roots, the RAM-guided strategies will help maintenance operations to adjust more rapidly to and incorporate the new fleet when it arrives, by focusing on the preservation of system functionality and infant mortality that should be expected upon the implementation of any new system. Through the application of RCM in the existing fleet and the resultant adaptation of new or improved SOP, frontline personnel would be acclimatized to change and change management. The ability to cope with change will be required for the integration of the new fleet. [**8**]

From the RCM analysis and the resulting PM tasks, focus should be given to the equipment required to do those tasks as developed through the RCM program. Any consideration of acquiring new equipment as a result of these needs should also take the requirements of the new fleet into consideration. From the progression into Lean Maintenance, the relative importance of the equipment may then be established. If and when possible, equipment that is replaced should be able to be used on both the existing and the new fleet. [**16**]

Through the improved communication and problem solving skills acquired from the MDW® program, integration with the new fleet and fleet-related equipment will undoubtedly be streamlined. The greater understanding of current equipment would also aid in expediting the adaptation of new equipment. [**47**]

A fundamental element of RCM is the investigation of the ROI of any maintenance activity. If the condition of the equipment has deteriorated to such an extent that normal maintenance activities are no longer feasible, then an investigation is required. The investigation should determine if a general overhaul, an upgrade or replacement is the most feasible option. Much of the existing rolling stock is nearing the end of its life-span. The work done due to RCM will greatly contribute to establishing when and how it should be decommissioned, refurbished or upgraded. This will also have implications for the rollout rate of the new fleet and timing the deliveries in such a way that they best support the core functionality of Metrorail. [**8**]

A final aspect that needs to be considered is the general overhaul that normally takes place every 8 to 12 years. By focusing on function retention, RCM would highlight areas that should not merely be overhauled, but actually upgraded or redesigned. During this upgrade/redesign, commonality between the new and old fleet should to be considered. Great potential exists for learning from the new fleet and applying some of these improvements to the existing fleet through the general overhaul mechanism. [**6**]

5.3.5 HR Management and Training

According to Levitt [**17**] PM, and therefore RCM and TPM, require a higher calibre of personnel than an organisation that relies on CM/BM. Any move from predominantly TDM to more PdM would require an increase in the skill level of employees, particularly the frontline. Similarly, in order to manage the frontline employees, management would also need a greater understanding of PdM in general, but particularly the PdM tasks that they would adopt in their specific departments. Both RCM and TPM rely on the data and information gathered by the frontline and thus incorporate improvements based on this information. This improved feedback flow of information would influence the design and evolution of the continuously improving TPM and RCM programs. [**9**]

Frontline employees would need to have a good and thorough understanding of the equipment they are working on, in order to make the recommendations from RCM work. MDW® goes a long way to helping them understand their place in and relevance to the organisation, as well as the importance of the work they perform. To achieve this improved competence at all levels, a culture of continuous training needs to be developed. Just as the SOP and tasks should continuously improve, so too should the skills and level of training that all employees receive. The skill set and education required for a shift from predominantly TDM tasks to more PdM tasks would also influence the choice in people that are employed and the minimum requirements for a specific position. The initial training program for new employees also needs to aid in speedy integration with the mini business concept. The new employee training program would need to incorporate some MDW® training. TPM through MDW® will also help identify and highlight skills shortages and be able to cater for specific training needs of individuals. [**47**]

The current understaffing, with some estimates as high as 40%, is not an ideal situation. [**30**] However, it does present an opportunity for recruiting people with a higher skill set, to suit TPM and future Lean Maintenance rollout. It also presents an opportunity with regard to employing people once the new fleet begins arriving. Consideration needs to be given to employing or training suitable people to work on the new vehicles that should start arriving in 2015. [**3**]

Just as TPM could change the structure of training and hiring, it would also have an effect on the way the support operations see their role in the business and how they contribute to achieving them. By applying MDW® to the support departments, a greater understanding of the internal customers would be fostered. This is also the case in HR, where Rolling Stock, Infrastructure and Operations are the direct internal customers of the services that HR provides. A greater understanding of its customers would improve the service they provide to these departments. This would also be the case with all the other support departments. [**47**]

5.3.6 The "Make or Buy" decision?

During phase 1 of the roadmap, the questions of what needs to be done when and how best to do it would be answered. However, the knowledge and skill set acquired through TPM would only exist within Metrorail/PRASA and not automatically with its suppliers. Great care needs to be taken with regard to the "make or buy" decision. Through RCM, the ideal maintenance tasks and intervals may be established. If these tasks require skills and technology that do not exist within Metrorail, it would either have to be acquired or the task would need to be outsourced. The first and most fundamental way to decide whether to make or to buy is to consider ROI. If the work performed by an outsourced supplier is of equal or better quality than is possible from within the organisation, and the cost of outsourcing is cheaper, both now and in the long-term, then the task should be outsourced. The basic advantages and disadvantages of the "make or buy" question would still apply within phase 1. Some of the advantages and disadvantages of outsourcing are listed in table 8 below. [**8**]

Advantages	**Disadvantages**
Reduce the impact of high labour turnover within own organisation.	Less managerial control.
Increase efficiency due to higher expertise.	Dependence on supplier, especially if sole source supplier.
Reduce labour cost.	Possible higher cost, due to supplier wanting to make profit.
Improve own core business focus.	Security and confidentiality issues.
Acquire specialised services or skills quickly.	Hidden costs.
Increased flexibility due to supplier choice.	Quality problems.
Develop internal staff through co-operation with external staff.	One of many customers, thus might not always receive priority.
Requires less capital when moving into new field or expanding.	Negative publicity for internal staff.
Improve project start-up time.	Trade unions want to keep control.
Less management required.	Government laws that favour labour intensive actions.

Table 10 Advantages and disadvantages of outsourcing [40] [41]

A secondary aspect, once the "make or buy" decision has been made, is the relationship between PRASA/Metrorail and its current and intended suppliers/partners. The supplier agreements and the structure and nature of the relationships need to function in such a way that any future PM strategy can be implemented successfully. The interdependence and cooperation between Metrorail and its suppliers are areas where the roadmap can and needs to have an impact. [**8**]
In some cases, outsourcing is used to outsource problems. On some occasions this has worked, but in many others it has failed. Outsourcing a problem does not solve the problem, but rather moves the problem to a different part of the supply chain and, if that part of the supply chain cannot solve the problem, the effects will still be felt. Often this is due to the cause and effect of a problem not being found together with the effect of a failure. Failure mode analysis on both a management and maintenance level can address this and would help to identify when outsourcing should occur and when tasks should remain in house. [**9**] Within the RCM analysis into wheels (section 6.2), the question of "make or buy" is considered.

5.3.7 Standards and Standardisation

The focus of RCM is to ensure and improve the sustainment of system functionality. [**8**] However, the implementation of RCM needs to be done in such a way that the system functionality is retained during the implementation thereof. However, as part of RCM, some practices and procedures may need to change so that the result thereof will be improved system functionality. Based on the application of the Pareto principle to the rolling stock and infrastructure, the SOP of the top contributors to unscheduled downtime should be reviewed first. They would, where necessary, be updated, revised or changed completely, so that the resulting SOP should be able to better preserve the system functionality and, where possible, improve it.

With regard to standardisation, special attention should be given to the general overhaul procedure for the following reason: Metrorail is currently already operating numerous different types of motor coaches and plain trailers; this is set to grow once the new fleet arrives. The new fleet requirements would further complicate the supply chain as well as the maintenance operations. Although costly, an upgrade during the general overhaul to improve part commonality between different coaches would simplify and standardise the supply chain. [**20**] The potential upgrade during the general overhaul can be guided by the knowledge gained from the application of RCM, where the areas that would achieve the highest ROI through a redesign and upgrade will be highlighted and thus focused on. The second aspect with regard to commonality is the new fleet. If possible, the ability to upgrade the existing fleet to share commonality with the new fleet should also form part of the purchasing decision.

Neither RCM nor TPM deal specifically with the requirements of the Health and Safety Regulations and the Railway Regulator. This is a challenge that needs to be overcome. The integration of the Health and Safety Regulations, the laws and guidelines from the Regulator and the existing SOP require special attention. [**23**] SOP need to exist in such a way that they adhere to all the regulations and requirements in one procedure and not have multiple SOP that run parallel and could cause unnecessary overlapping, redundancy or uncertainty. Moreover, as much as senior management needs to understand RCM and TPM, so too should the Railway Safety Regulator (RSR) in order for necessary changes to be made to the regulations when appropriate. [**15**] [**8**]

A key part of reviewing the SOP is the review of the current scheduled maintenance (henceforth referred to as shedding or shed) operations and the activities that occur during a Full Shed, an Intermediate Shed and Passenger Safety & Comfort (PS&C). [**49**] This includes establishing why the current timetable exists and how it should change/remain. This is discussed in greater detail in chapter 6.3.

5.3.8 The Top and Bottom of the Organisation

The principles of RCM and TPM are more than just maintenance principles; it is also management principles. The implication of this is that these are not just strategies and processes that the frontline needs to follow, but rather principles that need to pervade all levels of the organisation. [**23**] For it to be successful, any strategy requires commitment, determination and involvement at all levels, from the frontline (the bottom) to the CEO (the top) and his team. The same applies to this suggested roadmap. Through RCM and the requirement-based approach, this roadmap would allow maintenance practices to be designed where they are required. It will however, need support, involvement and motivation form the top down. [**47**] [**8**]

To understand the degree of involvement required from all levels, TPM needs to be viewed not simply as a strategy, but a corporate culture. [**17**]. It needs to be a long-term, corporate lifestyle change, which they would need to understand, embrace and allow to influence the way they run the organisation. It would mean that training would be continuously needed throughout the organisation, from Head Office down to the frontline. There are different TPM derivatives, two of these are Total Productive Manufacturing and Total Productive Management. At their core they share the same principles and the application of these principles would be beneficial throughout any organisation. [**16**]

All levels of the organisation need to understand that because both RCM and TPM need to become a culture and a lifestyle, they would require considerable time to bear fruit. Strategies derived from the RAM policy are not quick fix solutions that promise to help the immediate financial standing of Metrorail. RAM, as a policy, seeks to guide organisations to focus on long-term sustainability and improvement, both functionally and financially. [**15**] [**16**] [**8**]

RAM, its derived strategies and the roadmap would require buy-in at all levels, both inside and outside the organisation, specifically from government and trade unions. The need for this far-reaching policy and program needs to be understood and supported, so that if, for example, the analysis reveals that the current shedding cycle and associated operations no longer constitute the most suitable PM strategy, the support and willingness to change the cycle would need to be present at the top. [**6**]

5.3.9 Special Cases

As was mentioned in some of the previous sections, three special cases will be investigated in this thesis to further validate the proposed policy with the suggested roadmap. The analysis and choice of these three cases will be discussed in the relevant sections to follow. The first case looks at the Top 7 faults as derived by Metrorail. The second considers the current state of wheel maintenance, specifically in the Western Cape region. The third is an investigation into the current shedding cycle and looks at possible long-term and short-term changes.

6 The three areas of application

This chapter briefly discusses the three areas where elements of the proposed roadmap have been hypothetically implemented in order to validate the roadmap and, by direct implication, the policy as well. The process of selecting these areas is discussed before the links between them are established.

Although a RCM analysis focuses directly on PAM, the principles and guidelines may be applied throughout the organisation. [**8**] This is specifically applicable for higher levels within the Rolling Stock Planning Department. One of these principles forms part of step 1 of the RCM analysis. Step 1 includes the selection of the system that is to be analysed and this selection is achieved by means of a Pareto analysis. Before performing a completely new Pareto analysis, the author investigated the possible existence of similar current activities. This investigation revealed that the Rolling Stock Planning Department does a similar analysis where the areas of greatest impact are documented. This analysis is known within Metrorail as the Top 7. [**50**] [**49**]

The first application area is thus the process related to generating the Top 7 list (chapter 6.1). The purpose of the investigation into the Top 7 is to establish the current procedure, evaluate the suitability and impact that the Top 7 has and make recommendations based on the guidance from the policy and the proposed roadmap.

From the Top 7 analysis it was discovered that one of the biggest challenges that face PAM operations of the Western Cape Metrorail region is wheel-related maintenance. [**32**] [**36**] The second application area was thus derived from the results of the first. It is an investigation into wheel set maintenance, which is discussed in Chapter 7. An investigation into wheel set maintenance is more technical and tangible than the Top 7 investigation. This has the consequence that the wheel set investigation forms the largest of the three application areas. The application to the wheel sets concludes with recommendations, with the potential impact of these recommendations expressed financially. It also reveals some of the knock-on effects of the wheel set shortage. The largest of these is the effect on the scheduled maintenance cycles.

The third application area is the scheduled maintenance cycle (or shedding cycle) of the rolling stock. In chapter 6.2 the effects of the wheel set shortage are discussed. One of these is that train sets need to be shortened and/or split to form new train sets. This complicates the planning process and has an impact on the shedding cycle. The implications, areas of concern and proposed solutions are discussed in chapter 6.3.

The purpose of these three applications is to validate how the application of the proposed policy and its derived roadmap can benefit Metrorail. The applications thus also form part of the validation process of the policy. The contribution that each area could make to the organisation, and therefore towards the validation, is explained in each of the following three chapters, in which the application to each area is also discussed.

6.1 Top 7 Analysis

The analysis of the Top 7 came about through the Pareto analysis required as part of RCM. This chapter outlines the current procedure and its origin, as well as the recommendations for the Top 7 process based on the PAM policy and its derived maintenance strategy roadmap.

6.1.1 The current Top 7 analysis procedure

The Top 7 is a monthly report that is generated by the planning department of Rolling Stock. The primary focus of this report is the analysis of the faults that occur during train operations and thus have the greatest direct impact on Metrorail passengers. The Top 7 lists the seven fault code areas that contribute most to train delays and cancellations. The entire list of fault codes may be viewed in Appendix D. Table 11 below lists the fault code groups. [**51**] Each group is roughly based on a sub-system in a train set. [**50**]

Fault Groups	
Fault Group Label	**Fault Group Description**
A	Compressed Air & Valves
B	Brake Equipment and Vacuum Systems
C	Cab and Body
E	Electrical Control Equipment
G&I	High Voltage & Body
H	Heaters
M	Traction/Auxiliary Machine & Controls
O	Doors
P	High Voltage and Switch Equipment
U	Draw Gear
X	Wheel/Axle/Bogie
Z	Fire Extinguisher

Table 11 List of Fault groups that faults are sub-divided into [50]

Similar to the train sets operating only on their designated lines, the Top 7 are evaluated for each of the three Western Cape regions. In each case, the fault groups are evaluated according to their impact and not the frequency with which they occur. The top seven fault groups are presented as a percentage of the total service interruptions, including both delays and cancellations that occur. The general process is mapped in figure10. [**50**]

Figure 10 Process flow chart of the procedure that is followed to develop the Top 7 faults report

From the Top 7 process map, it is clear that the final step in the process is the collection of the Top 20 actual faults. These are the specific faults - not fault groups - that occur most frequently. All this is done in order to allow Head Office to know exactly where they should focus their attention. Within the Top 7 document there is a second section that focuses specifically on all the faults that are picked up on during the shedding procedure. It is a list of fault codes along with the corresponding rate at which they have occurred during the last month and no further analysis by the Planning Department is done with regard to these faults. Neither the seven most frequent faults groups nor the top 20 specific faults are evaluated. Furthermore, the planners that compile the monthly Top 7 report receive no feedback from Head Office. [**50**]

The data for the Top 7 from May 2011 to October 2011 is presented in three different formats below. Each representation is followed by a short discussion. [**49**]

Fault Description & Group		**Month**						**Six month average**
		May	Jun	Jul	Aug	Sep	Oct	
Electric control equipment	**(E)**	128	116	96	109	93	96	106
High voltage and switch equipment	**(P)**	41	47	40	44	42	42	43
Traction / Auxiliary machine and controls	**(M)**	35	22	33	26	19	36	29
Brake gear	**(B)**	14	18	19	17	9	21	16
Cab and Saloon doors	**(O)**	10	8	4	9	6	9	8
Air related	**(A)**	13	10	6	6	11	10	9
Pantograph	**(G)**	5	10	6	3	8	6	6

Table 12 Collection of six-month fault code frequency data [49]

Table 12 shows the number of critical faults that occurred per fault group, per month, during scheduled train operations. These are critical faults, as they all caused delays or cancellations. Faults that did not cause delays or cancellations are not included. Of these faults groups, B, O and A do not cause the train to be directly inoperable; they are, however, safety concerns that, by law, require the train set to cease operations.

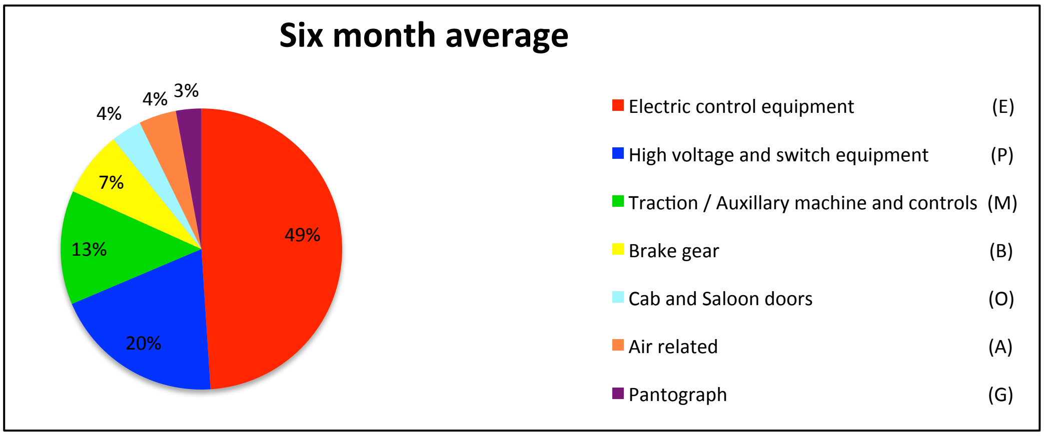

Figure 11 The six-month average fault frequency represented in pie chart

The pie chart in figure 11 shows the average distribution of faults per fault group. It is clearly evident how significant the electric control equipment faults are. The two most frequent fault groups both include electrical and electronic components. As was discussed in section 2.2.1, different types of components show different age-reliability profiles. Electronic and electrical components generally have a totally random failure probability [**8**]. This means that both Time Directed Maintenance (TDM) and Predictive Maintenance (PdM) are normally ineffective in improving the reliability of these specific components.

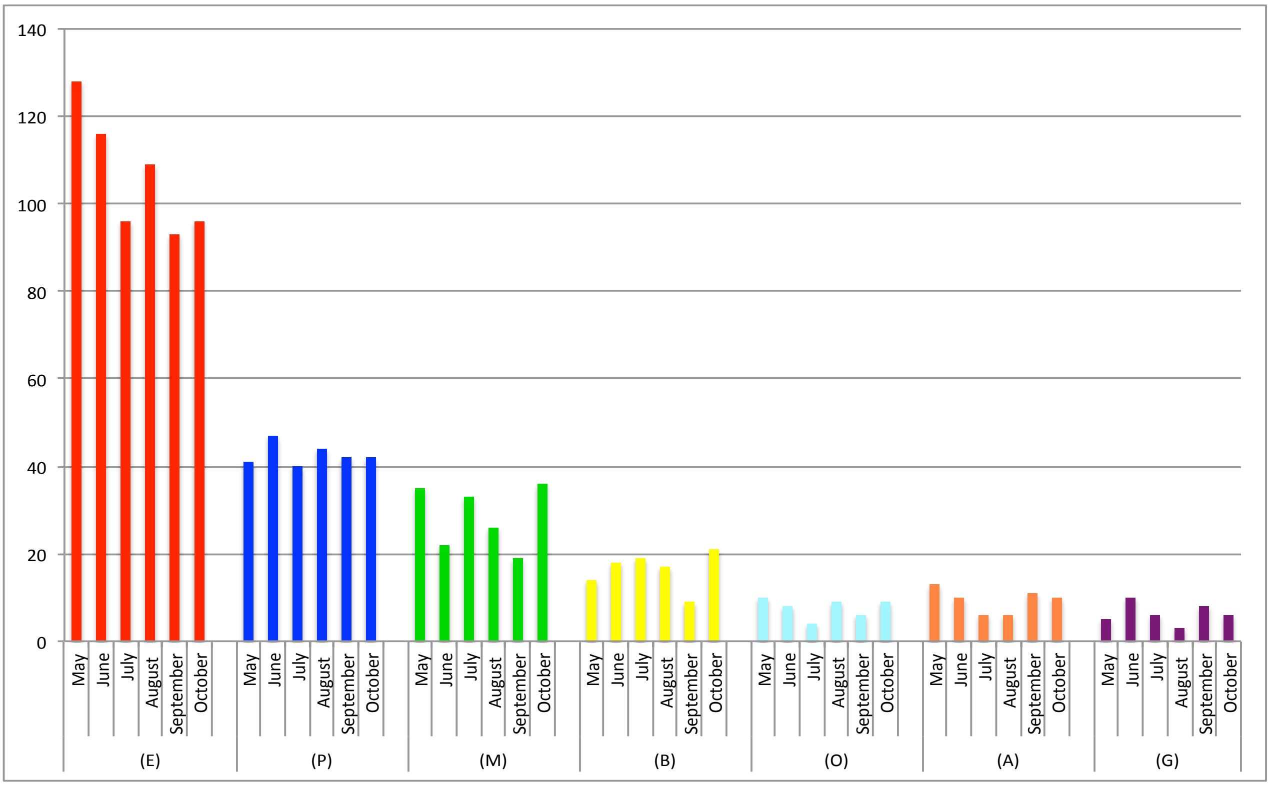

Figure 12 A bar chart representation of the six-month fault frequency data

The final pictographic representation of the information in table 12 is figure 12. The purpose of this graph is to identify any trends that have occurred over the last six months. From figure 12 it is clear that the only fault group that has shown any continuous improvement, where a decrease in the number of faults is an improvement, is fault group E (electric control equipment). The improvement in fault group E is encouraging, but it is still the most significant contributor to the Top 7. The lack of improvement in any of the other fault groups should be addressed.

6.1.2 Recommendations for the Top 7 analysis procedure

The first recommendation is that regular feedback and communication needs to be established and maintained between Head Office and the planners from each region that set up the Top 7. By knowing exactly what Head Office is using these reports for, the planners will be able to better understand what is required and give the best and most suitable information. Feedback from Head Office would also encourage the planners and give them a sense of purpose. Head Office should also convey the strategy that is currently, or will be, pursued to address these faults, along with improvement targets and a time frame.

Head Office should utilise all the resources at its disposal when addressing the Top 7. The most important of these are the employees, specifically frontline employees. Not all information can be conveyed in a monthly report and the Top 7 report does not include context or specific circumstances. The information that can be supplied by the frontline in this regard is invaluable.

In addition, this Top 7 analysis should be duplicated for faults that are detected in the workshop. This proposed analysis will, henceforth be referred to as the Workshop Top 7. The Workshop Top 7 should focus specifically on all faults that cause a train set or coach to be stopped. The impact of stopped coaches and train sets has been severe and far larger than that of in service faults. To illustrate this, consider the following: at the height of the wheel and other component shortage (May 2011), only 72 of the 85 train sets in the Western Cape region were operational, with 42 of these being shortened train sets. A shortened train set is normally only shortened by one coach per set. The average train set length is 11 coaches. [**32**] Each train set does an average of 3 trips per day (when balancing workday and weekend demand). The effective cancellations as a result of this are shown in figure 14, where the total Top 7 value is the sum of all the faults in May.

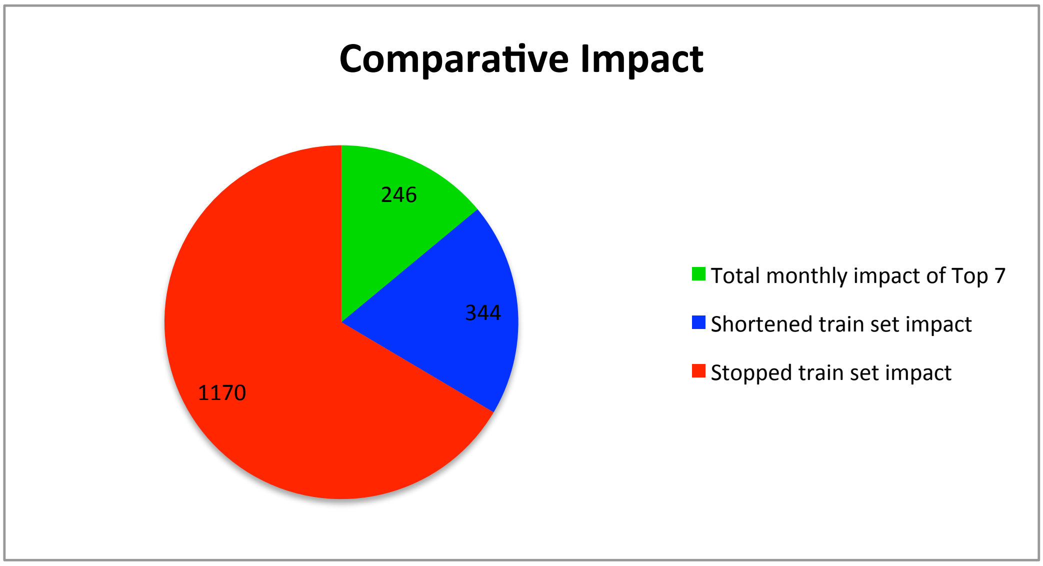

Figure 13 Comparative impact of unavailable train sets compared to the combined total of the Top 7

As is shown in figure 13, the Top 7 faults added together only contribute about 14% to the number of cancelled train trips. This revelation resulted in an investigation into what the largest contributors are to the Workshop Top 7, which led to an investigation and application of the proposed PAM policy into the wheel shortage. This investigation is discussed in Chapter 6.2.

The final recommendation for the Top 7 analysis is that, as per the proposed roadmap, an RCM analysis should be conducted on the systems that provide the largest contribution to both the original and workshop Top 7. The analysis should focus on the electric control equipment group, the high voltage and switch equipment group and the traction/auxiliary machine and controls.

6.2 RCM in Wheels

This chapter is structured as follows:

Background information with regard to wheel maintenance is provided, along with as much wheel related information as necessary to perform an RCM analysis thereof. The first seven steps of the RCM program are then applied. Finally, the results of the application are recorded and discussed.

6.2.1 Background to Metrorail wheel maintenance

As was explained in section 3.2, when Metrorail was separated from other Transnet operations, most of the maintenance facilities remained with Transnet and a separate business unit called Transnet Rail Engineering (TRE) was created within Transnet to deal with all rail related maintenance. [**26**] Due to this split, Metrorail, and thus PRASA, did not retain the facilities for, nor the ability to perform their own maintenance on wheel sets. This has caused Metrorail, specifically in the Western Cape, to be entirely dependent on TRE for wheel-related maintenance since 1998. [**25**] The only wheel-related functions that Metrorail perform are the inspection, removal and replacement of wheel sets.

The risks of sole source dependence were brought to the fore in 2009, when PRASA initiated a cost containment exercise, to bring the spiralling operational cost under control. The merits of such an exercise do not form part of this document, but should be investigated to evaluate the impact thereof. As a direct result of this exercise, Metrorail was unable to pay TRE for work done on its wheel sets for nine months. This had the direct result that no newly refurbished wheel sets were available for that period, and that the relationship between Metrorail and TRE deteriorated.

During that time, Metrorail did not cease operations and replacement wheel sets were still required. This resulted in using up the spare wheel set float that Metrorail had. Since the recommencement of payments and deliveries between Metrorail and TRE, the backlog of wheel-related maintenance work has not been reduced. The total number of required and planned wheel sets to be refurbished is shown in figure 14. [**34**] [**25**]

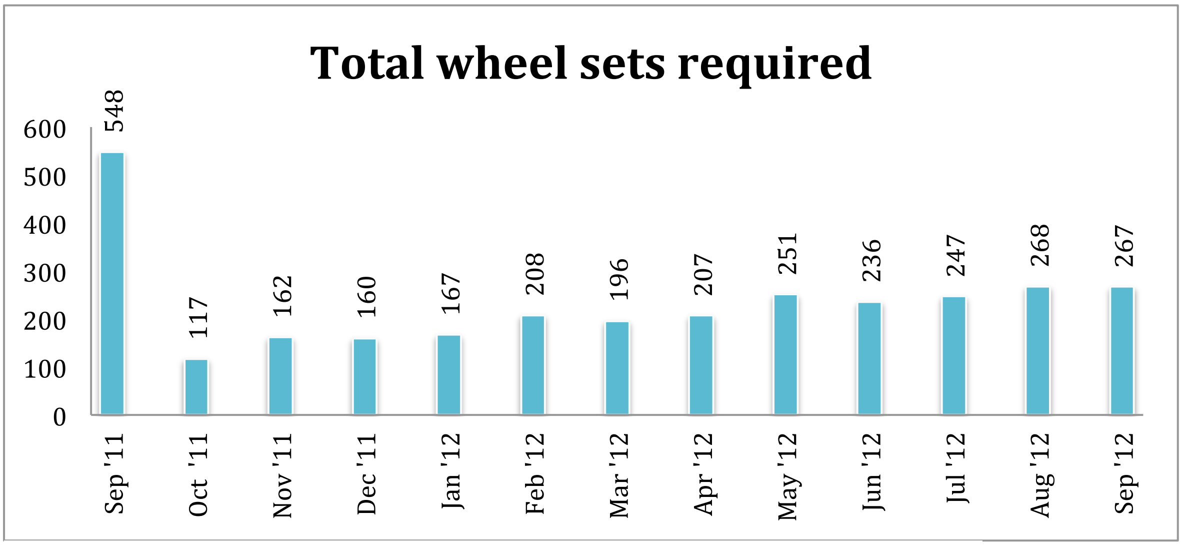

Figure 14 Wheel set maintenance demand forecast [29]

As is clearly evident from the chart, the backlog of wheel sets that should have been refurbished by September 2011 is significant. In fact, it has not decreased since delivery from TRE to Metrorail resumed two years ago. [**34**] The seriousness of the backlog, as well as the expected demand for the coming year, are highlighted when contrasting them to the actual TRE output for the last six months (April 2011 to September 2011), which is shown in figure 15. To visualize the problem accurately, the vertical axes scales are identical in the graphs in both figure 14 and 15. [**34**]

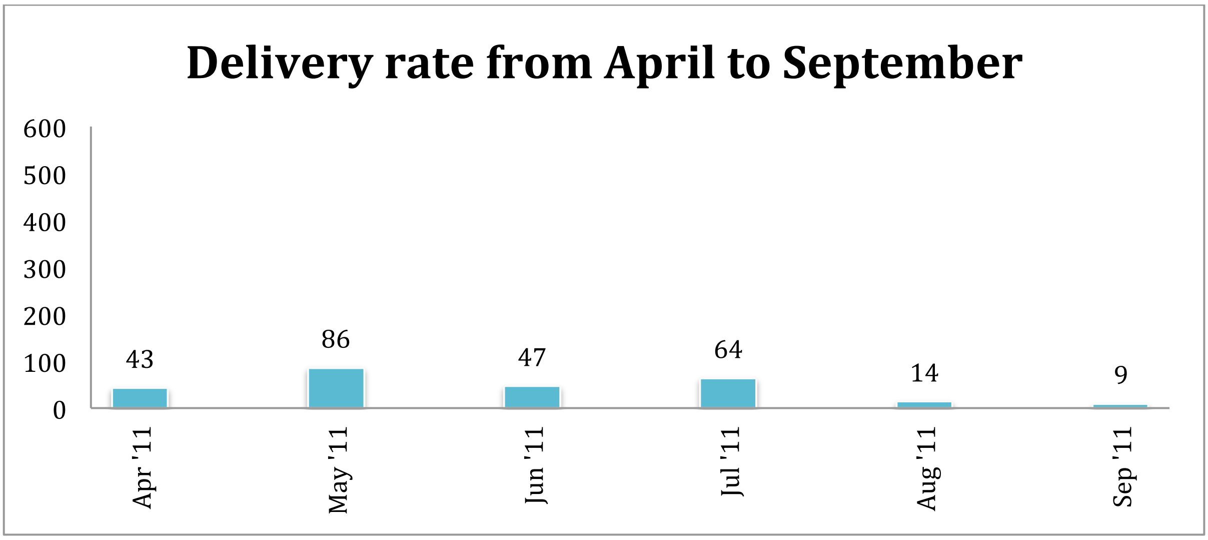

Figure 15 Delivery rate of wheel sets from TRE to Metrorail between April 2011 and September 2011 [29]

As is evident from the graph, the TRE output does not approach the required output. It has also been decreasing since May (excluding July 2011). This presents a very challenging future for the Metrorail Western Cape region. [**34**]

6.2.1.1 Effects of the wheel shortage

The wheel shortage has grown to such and extent that train sets have had to be shortened and coaches parked until they receive refurbished wheels. Train sets have been separated and those with wheels still within specification have been combined to form different sets. [**36**]

In order to predict the wear accurately and identify problem areas, train sets are supposed to operate only within their corridors. [**10**] The Western Cape region has three such corridors i.e. North, Central and South. Due to the lack of wheels and thus a lack of available coaches, train sets no longer operate where they should, but where the need is greatest instead. [**25**] Coaches from split sets also operate in different regions. The greatest problem that this causes is that, with the Metrorail PAM system heavily geared towards TDM, train sets are no longer operating under the same conditions and so their usage and wear rates change. [**32**] This in turn causes the shedding cycles to be unsynchronised, with train sets being over-maintained or under-maintained, or both. To illustrate this, consider the following example: A train set that is broken up at Full Shed and is joined to another that has only received a PS&C will have to come in for a Full Shed as soon as the PS&C set is due again, or miss the Full Shed required and only receive the Intermediate Shed. This increases both cost and risk. This impact has resulted in a specific investigation into the shedding procedure in chapter 6.3.

A knock-on effect of having to park stopped coaches is that these coaches, which only require wheels to become operational, are often cannibalised and vandalised. Although wheel sets are the most common items that are unavailable, other parts are also in short supply. When components and parts are required, they are then removed from stopped coaches for use in other coaches. If the required wheels then become available, stopped coaches still can not be returned to operability due to the other missing components.

The lack of available wheel sets has resulted in wheels being used up to their allowable tolerance, which has resulted in an increase in the wheel profile measuring to such an extent that almost every wheel is measured during each shedding event, be it a Full, Intermediate or PS&C shed. This requires extra man-hours and measuring equipment. [**34**] [**25**]

6.2.1.2 The normal wheel PAM procedure

This section discusses how wheel maintenance normally occurs. It describes the actions that take place at Metrorail, as well as the actions that take place at TRE.

There are five different types of wheel sets throughout the Metrorail fleet in the Western Cape region. [**34**] On average, each wheel set should, under normal wear circumstances, be reprofiled every 21 months for a tyred wheel and every 50 months for a solid wheel. Reprofiling is the term used for machining the contact surface of the wheel back to the ideal shape. A wheel needs to be reprofiled once it exceeds any of the maximum or minimum tolerances as set out by the RSR. As the wheel wears, it becomes less efficient and eventually, unsafe. According to the PM plan, as set out by the SARCC-Metrorail main agreement, the profile of the wheels is usually only measured during a Full Shed and only inspected during an Intermediate and PS&C shed. But, as has been mentioned, due to the shortage of wheels and wheels being run to the limit, the profiles are now being measured at every shedding procedure. During shedding the possible errors or fault codes are assigned. Table 13 lists the wheel/bogie/draw gear faults that can possibly be assigned. [**51**] [**25**] [**34**]

Wheels/Bogie/Draw Gear Faults
Skidded Wheel
Thin Flange/Tyre Down to Gauge
Loose Tyre
Cracked Tyre
Wheel grind
Gear wheel
Gear Case
Bogie frames
Inter bogie control
Draw gear
Primary and secondary suspension springs
Weight Transfer Equipment
Load Weighing
Air Suspension and Control
Horn Guide Liners

Table 13 List of different Wheel, Bogie or Draw Gear related faults [51]

If a wheel is found to be out of specification for any reason, not exclusively due to the profile being out of specification, the coach is stopped and sent to the lifting bay. Normally, train sets consist of the same coaches and are not broken up, as the wheel wear is very similar on all the wheels. The entire train set is thus taken out of operation and is scheduled to enter the lifting bay. The basic process inside the lifting bay is provided in figure 16 below.

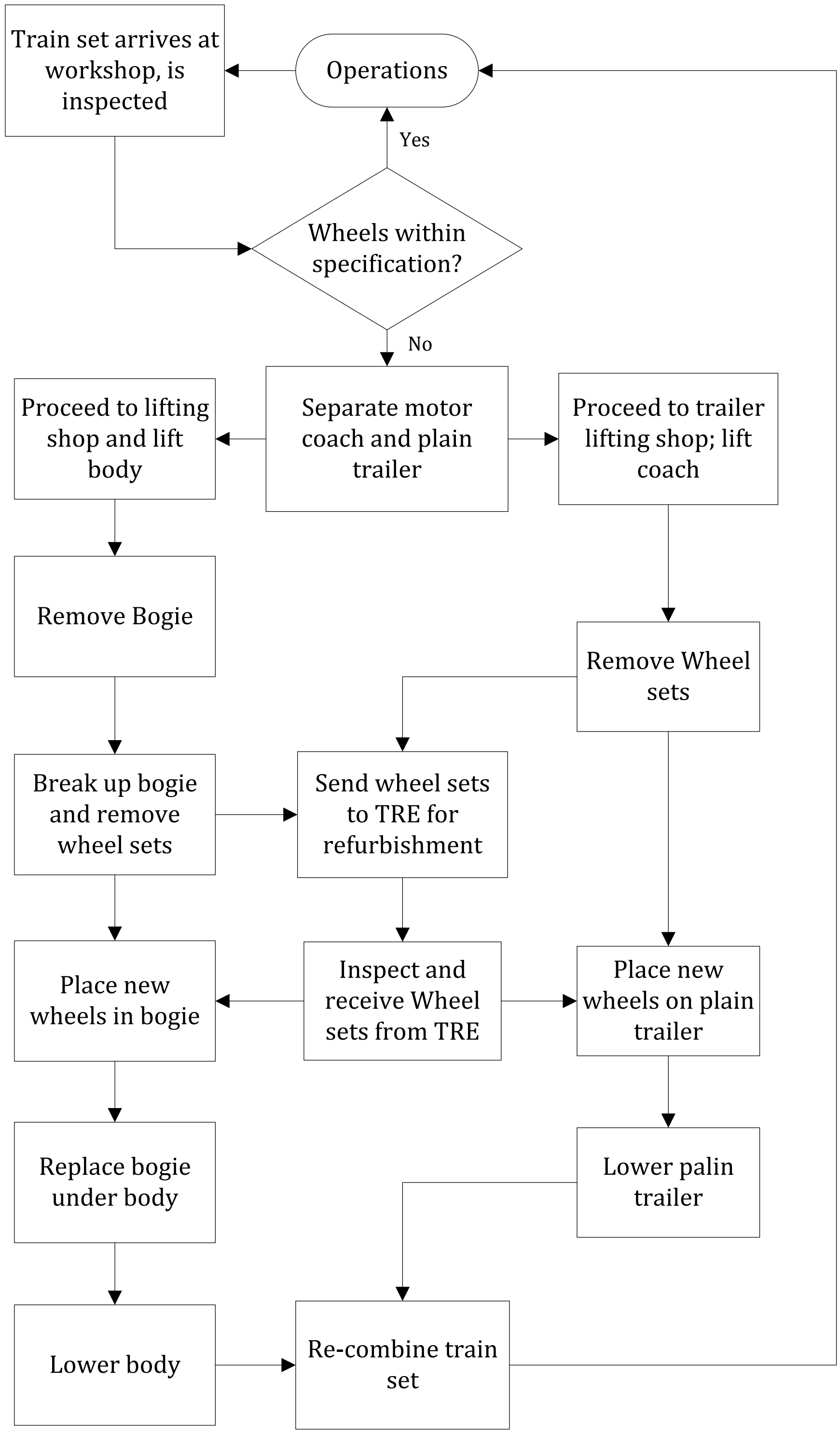

Figure 16 Process flow diagram of wheel set maintenance at Metrorail [33]

As is evident from the process flow chart, the actual maintenance is done at TRE. The process that is performed at TRE differs from wheel set to wheel set. The process of only one of the wheel sets is displayed in figure 17. The remaining processes can be found in Appendix E.

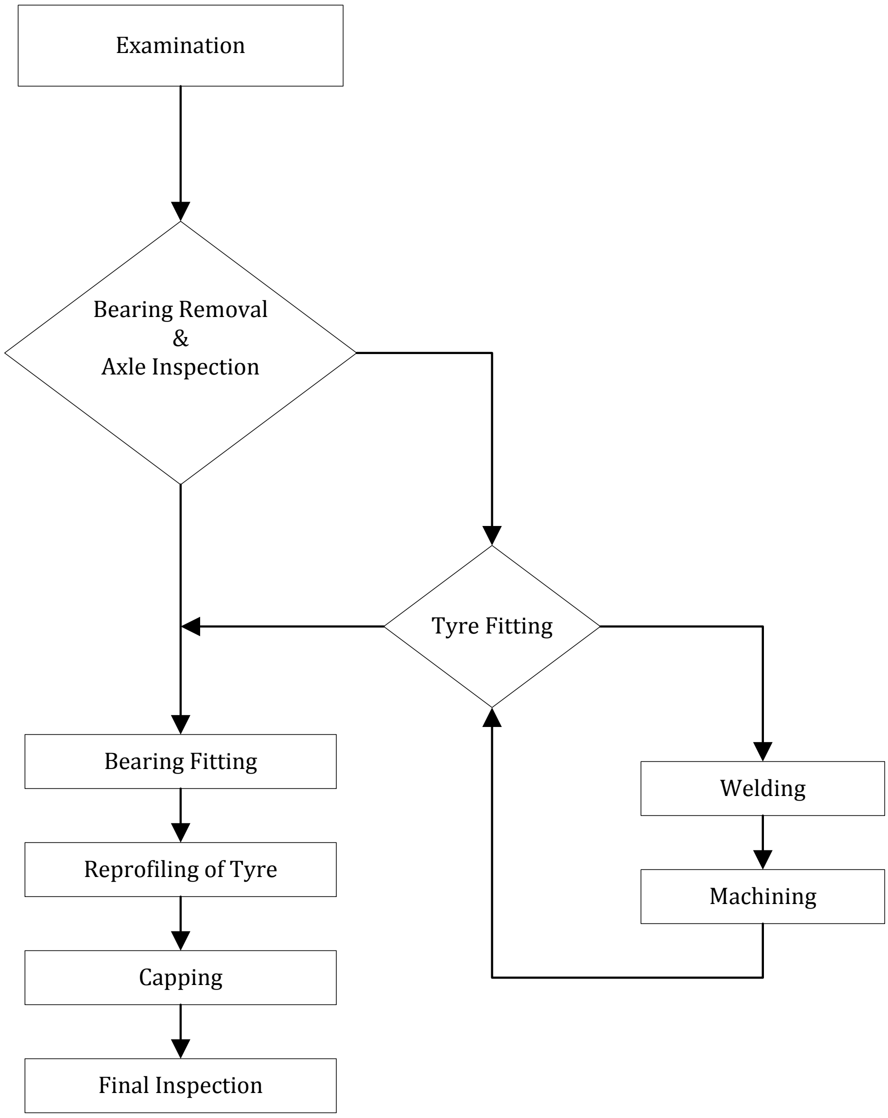

Figure 17 The TRE wheel set maintenance process of a plain trailer wheel set [33]

There are three (sometimes four) different levels of refurbishment that a wheel set can receive. They are light, medium and heavy. For the trailer coach wheels, the light service is split into two: light 1 and light 2. Table 14 shows which elements are included in each level of refurbishment, as well as the associated price. The prices in the table are the prices supplied by TRE for 2011/2012. [**52**] There are three different service variants depending on the type of wheel set. Only one of the three is shown below, the other two can be viewed in Appendix E. The table contains the corresponding costs from the process flow diagram in figure 17.

R3; R6 & SHV wheel sets		2011/12 FINAL PRICE				
Mainline and Trailer Coach Wheel		Prices	Typical valuation classes			
#	Task Description		Light 1	Light 2	Med	Heavy
1	Examine	R 508,00	R 508,00	R 508,00	R 508,00	R 508,00
2a	Reclaimable axle	R 1 164,00				
2b	Renew axle	R 14 008,00				R 14 008,00
3a	Reclaimable centres	R 1 751,00				
3b	Retyre	R 16 187,00			R 16 187,00	R 16 187,00
4	Convert for tyre	R 1 675,00				
5	Reprofile	R 510,00	R 510,00	R 510,00	R 510,00	R 510,00
6	C-Repair R6	R 620,00				
7a	Convert to APD (including adaptor, excluding bearings)	R 10 609,00				
7b	Convert to APD (excl. adaptor)	R 2 813,00			R 2 661,68	
8	Dalic bearing seat (one end)	R 1 182,00				
9a	Fit Recon bearing	R 3 099,00	R 3 099,00		R 3 099,00	
9b	Renew bearing	R 5 303,00		R 5 303,00		R 5 303,00
10	Spin test wheel	R 111,00				
			R 4 117,00	R 6 321,00	R 22 965,68	R 36 516,00

Table 14 Wheel set maintenance price breakdown from TRE [52]

The decision on which kind of service the wheel set requires is determined during the inspection at TRE. [**34**] Metrorail cannot anticipate whether it will be a light, medium or heavy refurbishment. Thus, when planning, the Planning Department can only estimate the type of service that TRE will perform, limiting themselves to forecasting either a light or heavy service, where the medium services are split between the two. About 90% of the outstanding and the planned work for the next 12 months comprises light refurbishments, with the remainder being heavy refurbishments. The turn-around time for some of the different wheel sets with different refurbishments is shown in table 15.

Turn-around time in working days			
	LIGHT	MEDIUM	HEAVY
5M2A OIL SLEEVE	55	48	105
5M2A CANNON BOX	54	46	71
R3/R6 & SHV	Unavailable	Unavailable	Unavailable

Table 15 Average turn-around times for different types of wheel sets [34]

The turn-around times are not normally available and were only calculated on the request from the author.

6.2.1.3 Current mitigation exercises

The wheel shortage has become so severe that in an attempt to not fall behind further, Metrorail is sending specially combined train sets to Saldanha (another TRE workshop), where the freight trains that transport iron ore are maintained. [**31**] The workshop in Saldanha contains an under-floor lathe of the type U 2000-400, manufactured by Hegenscheidt-MFD in Germany. [**53**] The system is installed inside the scheduled maintenance workshop under the train track. The train is shunted over the system and the wheels are measured, reprofiled and measured again, without being removed from the train. The tyre life or profile thickness needs to be sufficient to be reprofiled. Thus, the Metrorail train sets that are sent to Saldanha are a combination of different coaches from different train sets that meet the minimum specifications. The trip from Cape Town to Saldanha is about 200km. These train sets are completely unavailable for an extended period. The average turn-around time is between two and three weeks. The cost structure is broken up into transport and reprofiling cost. The cost of driving a train set to Saldanha is R 2 530 and the reprofiling cost is R 2 605 per wheel set. At the time of writing, Metrorail had sent and received six train sets to and from Saldahna. [**31**]

The second mitigation exercise to alleviate the wheel shortage is to send wheel sets to Johannesburg by train, to be refurbished. Wheel sets are removed from coaches, loaded into a converted car carrier wagon and transported as part of a Shoshaloza Meyl train. Once refurbished, they are loaded back into the converted car carrier and transported back to the Western Cape. The first trip is scheduled to take place in late 2011 or early 2012. Due to the acute shortage, however, wheel sets are being sent by road transport until the conversion of the car carrier is complete. The recondition pricing for the wheel sets in Johannesburg is comparable to the TRE pricing. Yet, no funds have been budgeted to the Western Cape region in the current financial year to cover transport costs. Thus, only wheel sets that require a heavy overhaul will be sent, as the financing for these comes from Head Office. This lessens the impact that can be achieved from having wheel sets refurbished in Johannesburg, as only about 10% of the wheels that require maintenance fall into this category.

The third POA is the purchase of a few hundred wheel sets that have been standing in Bloemfontein as part of decommissioned coaches. These wheel sets have been inspected and are in good condition, requiring only light refurbishment to become operable. The total cost to remove, refurbish and transport each wheel set to the Western Cape will cost R 2 700 on average, per wheel set. If this is compared to the price of a completely new wheel set (where heavy refurbishment alone costs R 36 500), the benefit of this arrangement becomes clear.

These wheels are being reprofiled in Bloemfontein and Johannesburg, where there is spare capacity. Deliveries are due to commence in mid December of 2011. This project will allow the total float of spare wheels to increase, enabling worn wheel sets to be replaced and more coaches becoming available. [**31**]

6.2.2 Application of RAM-recommended RCM analysis

This section deals with the analysis of wheel sets as a sub-system of a coach. The information required for steps 1.1 and 1.2 of the RCM analysis is discussed in the general analysis of the Rolling Stock in section 6.2.1, however, a quick overview is provided.

6.2.2.1 Step 1: System selection and information collection

The level of assembly that was chosen was the sub-system level. The choice ties in with step 1.2 of the RCM analysis where the Pareto principle was applied. Wheel sets are the largest cause of unavailability and their effect on availability is greater than the Top 7 faults. The analysis should be done for each different type of wheel set. However, through the investigation, it could be discovered that the recommended solution is applicable to all types of wheel sets. For the duration of the RCM analysis, the information, tables, flow charts and other document elements are all for plain trailer wheel sets, as these make up the largest percentage of wheel sets in the fleet. [**8**]

In step 1.3 of the RCM analysis, all the possible existing information is collected. A summary of the current procedure and circumstances has been provided in previous sections. Some of the remaining information can be found in Appendix E. [**29**]

6.2.2.2 Step 2: System boundary definition

A wheel set is a simple system. The boundaries are defined as follows: the wheel-track interface, the bearing box-to-suspension interface, the brake-to-wheel interface and, in the case of the motor coaches, the gear-to-motor interface. This information is summarized for plain trailer wheel sets in table 16.

Type	Boundary system	Interface location
In/Out	Wheel	Wheel-track interface
In	Wheel	Wheel-brake interface
In/Out	Bearing box	Bearing box-suspension interface

Table 16 RCM analysis boundary definition

6.2.2.3 Step 3: System description and functional block diagram

This is the analysis for a plain trailer wheel set. The other wheel sets are not specifically analysed the reason for this is discussed in section 6.2.2.1. Each wheel set consists of 1 axle, 2 wheels, 2 bearings and 2 Gibson rings. [**29**]

Functional description: The wheels are press-fitted onto the axles with bearings press fitted outside of the wheels. A steel tyre is fitted over the wheels. The Gibson ring prevents lateral movement between the tyre and the wheel. Rotational slip is prevented by the interference fit between the wheel and tyre. The bearing box forms the outer shell of the bearing and is mounted to the suspension. Brake pads push down on the wheel when necessary and slow down the train. The brakes are air powered, which means that sufficient air vacuum releases them from the wheel. In the event of a loss of vacuum, the springs automatically apply the brake pad to the wheel. A system block diagram is included below (Figure 18). [**25**] [**34**]

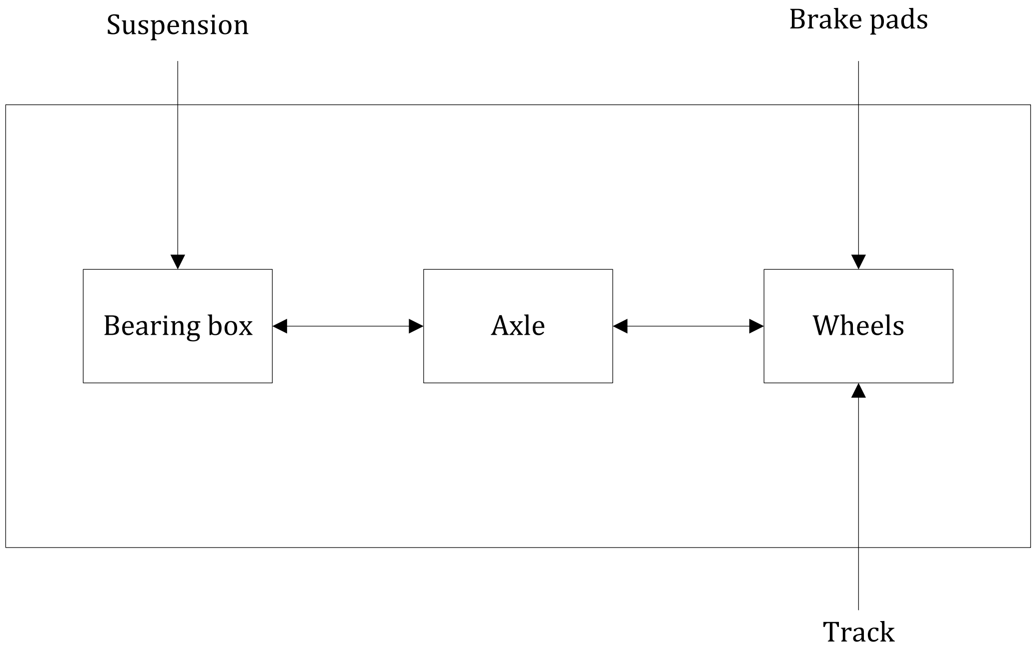

Figure 18 System block diagram of a wheel set

In the above figure, the boundary of the system is shown by the large rectangular block. It also doubles as a visual representation of the work breakdown structure. The next part of step 3 is the description of the In/Out interfaces: [**34**]

In interfaces

- Brakes – force applied directly to the wheel
- Suspension – connects the bogie/body to the bearing box
- Track – carries and guides the wheel set, thus the coach and the train set

Out interfaces

- Suspension – connects the bearing box to the body/bogie
- Track – Wheels rest on the track

Internal interface

- Bearings – Are press-fit to the axle and allow complete wheel set rotation
- Gibson ring – keeps the tyre on the wheel

The fourth part of step 3 is the Part Breakdown Structure (PBS). It is a list of all the components and parts that make up a wheel set. The PBS is shown in figure 20, where the numbers in the brackets after each item indicate the quantity of each component. [**34**]

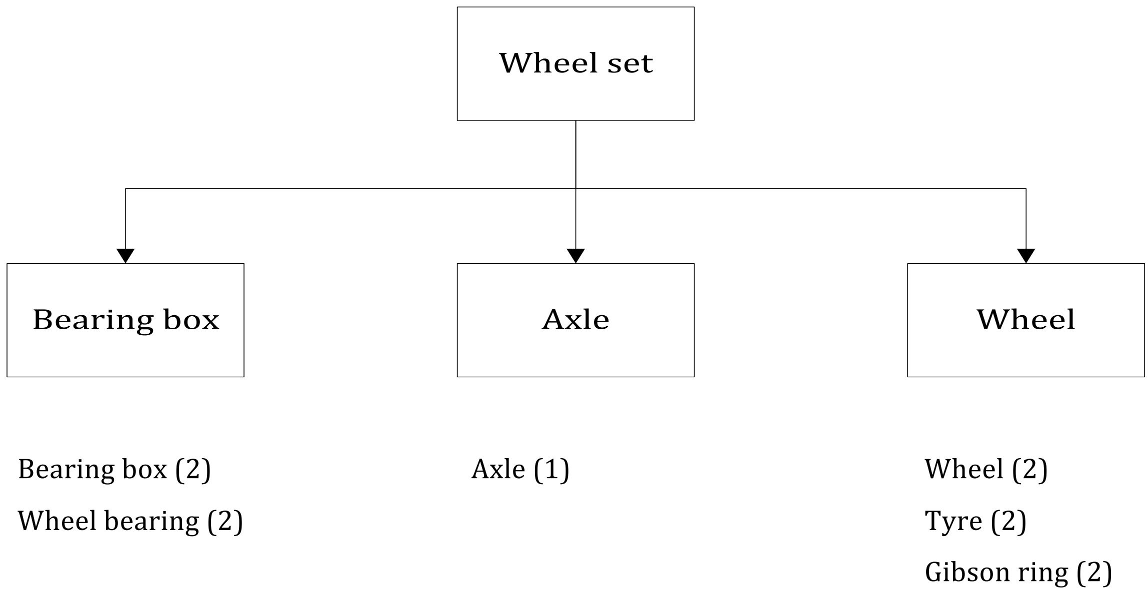

Figure 19 Part Breakdown Structure of a wheel set

The final part of step 3 is to review the equipment history. This has already been done in step 1 and the relevant information is included in all the sections preceding step 1. Further information is included in Appendix E.

6.2.2.4 Step 4: System functions and functional failures

In this step, all the functions are listed along with each possible failure for the respective functions. The relevant information has been summarised in table 17. [**34**] [**25**]

Function no.	**Functional failure no.**	**Description**
1.0 Wheels		
1.1		Remain in non-slip contact at all times
	1.1.1	Lifts/ Bounces of track
	1.1.2	Slides off track
	1.1.3	Slides on track
	1.1.4	Rolls off track
1.2		Make sufficient contact with break when required
	1.2.1	No contact when required
	1.2.2	Not enough contact force
	1.2.3	To much contact force
	1.2.4	Contact when not required
1.3		Wheel must maintain shape and structural integrity
	1.3.1	Wheel cracks
	1.3.2	Wheel loses roundness
	1.3.3	Wheel wears to outside of tolerance
2.0 Axle		
2.1		Remains connected to wheels
	2.1.1	Becomes detached from wheel
2.2		Remain attached to bearings
	2.2.1	Inferior interference fit
	2.2.2	Bearings seize
3.0 Bearing box		
3.1		Remain connected to bearing
	3.1.1	Box becomes loose
	3.1.2	Bearings seize and/or break
3.2		Remain attached to suspension
	3.2.1	Mounts break
	3.2.2	Mounts are loose

Table 17 A summary of the system functions and functional failures

6.2.2.5 Step 5: Failure Mode and Effects Analysis

Step 5 consists of drawing up two large tables. Only one of the tables is displayed in this section. The second table can be found in Appendix F. The first table is the functional failure matrix. This matrix shows which functional failures can be attributed to each component. It also allows for the cancellation of some functional failures that are duplicated. The functional failure matrix is displayed as table 18. The second table is the Failure Mode and Effects Analysis (FMEA) table, where all the possible failure modes (causes of failures) of each functional failure are collected and listed. This table investigates the entire effect of failures from component, to sub-system, to system, to the entire coach. This is a large table and can be found in Appendix F.

Equipment	No.	A	B	C	D	E	F
	Name	Wheel	Tyre	Bearing	Gibson Ring	Axle	Bearing Box
	Functional Failures						
Wheels	1.1.1 Lifts/ Bounces off track		(1)	(2)	x		(5)
	1.1.2 Slides off track		(1)		(6)		
	1.1.3 Slides on track		x	x			
	1.1.4 Rolls off track		x				
	1.2.1 No contact when required		x				
	1.2.2 Not enough contact force		x				
	1.2.3 To much contact force		x				
	1.2.4 Contact when not required		x				
	1.3.1 Wheel cracks	x	x				
	1.3.2 Wheel loses roundness		(1)				
	1.3.3 Wheel wears to outside of tolerance		x				
Axle	2.1.1 Becomes detached from wheel	x				x	
	2.2.1 Inferior interference fit			x		x	
	2.2.2 Bearings seize			(2)			x
Bearing box	3.1.1 Bearing box becomes loose	(4)		(3)			x
	3.1.2 Bearings seize and/or break			(2)			(2)
	3.2.1 Mounts break						x
	3.2.2 Mounts become loose						x
(1) Covered by 1.3.3							
(2) Covered by 1.1.3							
(3) Covered by 2.2.1							
(4) Covered by 2.1.1							
(5) Covered by 3.1.1							
(6) Covered by 1.1.1							

Table 18 Functional failure matrix table

6.2.2.6 Step 6: Logic tree analysis

The Logic (decision) tree analysis table is on the next page and is followed by and explanation.

Functional Failure	Component/failure Mode	Criticality analysis				Comment
		Evident?	Safety?	Outage?	Category	
1.1.1 - Lifts/Bounces off track	.01 - Becomes loose *(Gibson ring)*	Y	Y	Y	A	The probability is very low, but has happened
	.02 - Ring cracks (Gibson ring)	Y	Y	Y	A	Very low probability, unless caused by impact
1.1.3 - Slides on Track	.01 - Wheel fails to rotate at required revs *(Tyre)*	Y	Y	Y	A	Mostly brake related, or due to damage from impact
	.02 - Bearing seizes *(Bearing)*	Y	Y	Y	A	Bearings are changed at each reprofile event. No PM tasks at all
1.3.1 - Wheel cracks	.01 - Wheel cracks *(Wheel)*	Y	Y	Y	A	Crack due to impact, has a low probability, could result from heat damage
	.02 - Tyre cracks *(Tyre)*	Y	Y	Y	A	Same as above
1.3.3 - Wheel wears to outside of tolerance	.01 - profile outside of specification *(Tyre)*	Y	Y	Y	A	Most common fault; full PM program exists
2.1.1 - Becomes detached from wheel	.01 - Wheel internal diameter out of specification *(Wheel)*	N	Y	Y	D/A	Extremely low, requires quality control at (re)manufacture
	.02 - Axle exterior diameter out of specification *(Axle)*	N	Y	Y	D/A	As above
2.2.1 - Inferior interference fit	.01 - Axle is out of specification *(Axle)*	N	Y	Y	D/A	As above
	.02 - Bearing internal diameter/surface out of specification *(Bearing)*	N	Y	Y	D/A	As above
2.2.2 - Bearings seize	.02 - Bearing Box damaged/out of specification *(Bearing Box)*	Y	Y	Y	A	Very low probability; easy to identify visually/ultrasound
3.2.1 - Mounts break	.01 - Suspension mounts break *(Bearing Box)*	Y	Y	Y	A	As above
3.2.2 - Mounts become	.01 - Suspension mountings become	Y	Y	N	A	As above

The logic tree analysis is displayed in table 19. Due to the criticality, with regard to safety, all the faults form part of category A, with some of the faults also falling into category D, which contains the hidden faults. [**25**] [**34**] From the logic tree analysis it becomes clear that some of the root causes manifest themselves in more than one fault. During step 7 (task selection), many of the PM tasks are thus repeated for identical and similar fault causes.

6.2.2.7 Step 7: Task selection

The full task selection table is contained in Appendix F due to its size. The outcomes can be grouped into three major categories. The first is that the current TDM tasks that occur are required by the Regulator and are effective for current system conditions. The second is that there are no current PM activities for the bearings. The lack of bearing inspections is temporarily acceptable due to the bearings being replaced during each reprofiling at TRE. [**27**] Finally, the fault-finding activities occur during all scheduled maintenance operations due to safety considerations and their frequency and effectiveness are difficult to determine due to the lack of data. Any reduction in frequency requires a full investigation and evaluation of the safety considerations of each alternative.

The final component of the first seven steps in the RCM analysis is the sanity check, as defined in section 2.2.8. The only cause for concern is that there is no current PM program for bearing maintenance. From the RCM analysis it is evident how many different potential faults could occur due to bearing failure.

6.2.2.8 RCM conclusions

Although the results from the RCM analysis show that many of the current strategies are the best suited, the RCM analysis can still be considered successful. The discovery that Metrorail is currently not performing any bearing-related PM tasks is disconcerting. This discovery should warrant an investigation into the Regulatory requirements regarding bearing maintenance, as well as existing techniques that are employed at other railways around the world.

Currently, there are two types of inspection technologies being used to test and assess bearing condition. The first focuses on acoustic technology. Acoustic technology is based on bearings emitting specific noise at specific frequencies and pitch ranges. Bearings that are failing emit a noise outside of this range and can thus be detected.
There are different techniques and types of acoustic equipment. The two primary groups of acoustic technologies are trackside technologies and mounted technologies. Trackside technologies are fixed at specific locations along a rail network with multiple receptors that then measure the bearing condition as the train passes. Mounted technologies are built into each coach of the train set and monitor each wheel set continuously. [**54**] [**55**]

The second type of technology is thermal/infrared technology. The basis for this technology is that wheel set bearings operate within a specific temperature range. If bearings reach a temperature that falls outside of the established range, a failure is imminent. As with acoustic technology, there are two specific groups of technology, namely track side and mounted. The trackside technology investigates the bearings from the side either by a handheld device or strategically placed devices along the network. The mounted devices are generally temperature sensors that are placed near or even inside the bearing, with the latest of these informing the operator via radio signal of an imminent failure. Both types of inspection technologies require further investigation and should form part of further work. The author has included the above information as a springboard for further research. [**55**] [**54**]

As was mentioned at the end of the RCM section of the literature study, the real savings and improvements are sometimes discovered as a by-product of RCM analysis. This case is no exception. It is clearly evident that the current system is far from ideal. The biggest problem lies with the sizable backlog of reprofiling work that needs to be done. This backlog, along with its secondary effects and solutions, is an Item-Of-Interest (IOI).

An IOI is any idea, thought or solution that has been developed as a result of the RCM analysis, but does not necessarily form part of deciding what the best strategy and interval is. [**8**] The current backlog of reprofiling work and the lack of viable alternative supplier options are having a greater impact on the system functionality than the current PAM procedures of the wheel sets. The pursuit of retaining and maximising system functionality forms one of the core aspects of RCM, thus an investigation into an alternative to the Metrorail-TRE relationship is warranted and discussed in the next section.

6.2.3 Investigations of alternatives to TRE dependence

This section deals with an investigation into a long-term solution for the over-dependence of Metrorail in the Western Cape on TRE in the Western Cape. TRE is the sole local supplier of wheel maintenance. Past altercations have resulted in a significant backlog of wheel maintenance that has severely impacted the operations of Metrorail. In section 6.2.1.3 the current short-term mitigation exercises were discussed. This chapter will investigate the viability of Metrorail performing some of its own wheel set maintenance internally.

6.2.3.1 Insourcing alternatives analysis

There is currently no viable alternative supplier for long-term wheel maintenance. [**34**] [**25**] The viability of setting up a wheel workshop within Metrorail thus needs to be investigated. The paragraph below provides a quick overview of the current options available in the Western Cape and also presents the two primary alternatives for wheel set maintenance.

Each wheel set consists of one axle, two bearings, two wheel centres and two tyres. There are three different categories of wheel set maintenance activities. They are known as light, medium and heavy repair. The number of wheel set components that are repaired/replaced determines which category of wheel set maintenance is used. The current process involves removing the wheel set from the coach and sending it to a wheels workshop for repairs. There is only one such workshop in the Western Cape, namely TRE. If the wheel sets only require a light recondition, they need not be removed from the coach. In this case the wheel set is reprofiled by accessing the coach from below, either by lifting the coach or by placing the equipment under the track. The only such system that exists in the Western Cape is in Saldanha at another TRE workshop. [**31**]

The wheel set maintenance systems at Saldanha and Salt River represent the two primary systems that are used to perform wheel set maintenance. The under-coach system cannot exist independently of a full wheel set workshop, as it is limited to reprofiling. This investigation will establish which combination would best suit Metrorail.
The same company supplies the primary equipment used at both TRE in Saldanha and Salt River. The company is called Hegenscheidt-MFD from Germany. The author has had the privilege of visiting the Hegenscheidt-MFD assembly plant in Erkelenz, Germany, and saw the different machines and equipment available. [**53**] The financial analysis is based solely on Hegenscheidt-MFD equipment. In the first place, this is because they supplied the equipment used by TRE. As a result the cost, performance and capability figures are more readily comparable. Secondly, this investigation aims to evaluate whether Metrorail should invest in their own wheel set maintenance capabilities and not in which specific system or product is the most suitable.

There are three alternatives that Metrorail could pursue. The first is to acquire both a full wheel set workshop to perform all the required tasks. The second is to acquire both the under-coach system and wheel set workshop. The final option is to acquire only the under-coach system to perform the light reconditioning and rely further on TRE for the medium and heavy work. A full workshop installation requires large amounts of capital, highly skilled and trained employees, and significant construction time. However, the greatest factor in considering any alternative is demand. Figure 20 shows the forecast demand, which has been split between light reconditioning and heavy reconditioning. [**34**]

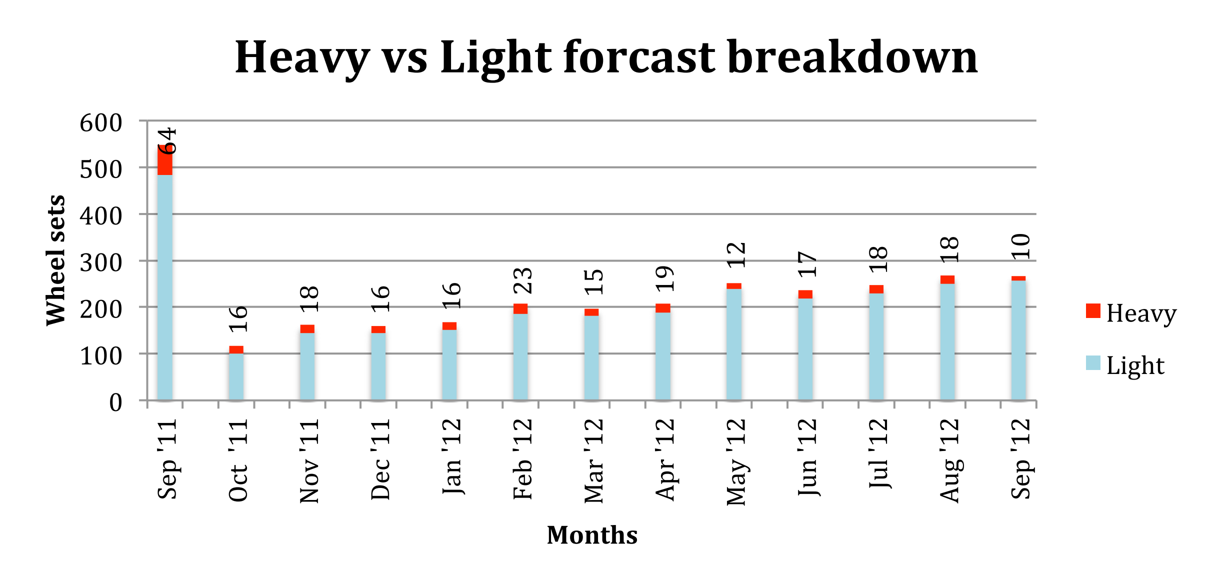

Figure 20 The forecast breakdown of light- and heavy wheel set repairs [29]

From figure 20 it is evident that less than 10 % of the wheel sets require heavy reconditioning, with a monthly average of 17 wheel sets. The primary and most expensive piece of equipment required for a wheel set workshop is a lathe. The capacity of the Hegenscheidt-MFD 165-CNC machine that is installed at TRE is 36 wheel sets per 8-hour shift. [**56**] Converting this to a monthly production capability results in a monthly capacity of 756 wheel sets, with one 8-hour shift per day and 21 working days per month. The estimated cost of equipment for a wheel set workshop is R 30 million, as per Hegenscheidt-MFD, compared to the under-coach option, with an installation cost of R15,74 million. [**56**] [**57**] The R15 million difference for the capability to recondition an extra 10% of wheel sets is not viable. Due to these findings, only under-coach options are considered further.

The conclusion of the application of the Pareto principle shows the same recommendation. The next section investigates the acquisition of the under-coach system exclusively.

6.2.3.2 Under-coach wheel set maintenance systems investigation

Until recently, the under-coach maintenance systems were limited to under-floor lathe systems. A cavity is excavated under the track inside a workshop and the machine is placed in this cavity. The recent alternative to this system is a track-based mobile lathe. The coach is lifted and suspended, whereupon the mobile lathe moves along the track under the coach and reprofiles the wheel set. [**56**]

For the purpose of investigating the viability of either type of under-coach systems, the two competing products produced by Hegenscheidt-MFD will be examined. Based on the requirements and specifications of Metrorail Rolling Stock, the following two products were deemed suitable and therefore investigated. The under-floor machine is a U2000-400, which is the same machine as is installed at TRE Saldanha, the second is the MOBITRUN®2. The detailed performance and capability figures are included in Appendix G and summarized details can be found in table 20. [**56**] [**58**] [**57**] The system acquisition price was quoted in Euros and converted to Rands at an exchange rate of 1:12. The production capacity figures are taken for one 8-hour shift per day, with 21 working days per month and 12 months per year. The installation cost for the U2000-400 is the estimated cost for digging and preparing the cavity under the track where the machine will be placed. The MOBITURN®2 requires no installation. The U2000-400 requires a shunting vehicle to move the coach or train set and the MOBITURN®2 requires a row of lifting jacks. [**59**]

	U2000-400	**MOBITURN®2**
Production capacity/year	3096	2748
Purchase cost	R11 640 000	R13 920 000
Installation costs	R1 500 000	R0
Shunting unit/ lifting jacks	R2 600 000	R22 220 478
Total	R15 740 000	R36 140 478

Table 20 A breakdown of the capital required to acquire each system [58] [57]

In order to calculate the Return On Investment (ROI), the operating costs need to be known. There is currently no MOBITURN®2 system in operation in South Africa. The operating costs of the U2000-400 could not be made available for this investigation. According to Hegenscheidt-MFD, the operating costs for both the U2000-400 and the MOBITURN®2 are very similar. [**58**] [**57**] In order to proceed with the ROI analysis, the operating costs of both machines were taken to be the cost that TRE charges Metrorail for each wheel set that is reprofiled by their U2000-400 at Saldanha. The cost per wheel set is R 2 604 per wheel set. [**31**] The ROI is calculated by using the potential cost saving by both of the potential machines compared with the continued use of TRE in Salt River.

The following assumptions are made with regard to the ROI analysis.:

- Due to the 2-week turn-around time for train sets sent to Saldanha, the resultant loss in revenue alone means that the comparison will only be made between TRE Salt River and the new machines. [**31**]
- The comparative cost used for TRE Salt River is the average cheapest light repair cost according to the ratio between motor coach and plain trailer light repairs as per the forecast.

- The lead-time for both the U2000-400 and the MOBITURN®2 is 10 months; it is thus assumed that the current mitigation efforts by Metrorail will have eliminated the backlog. This means that the forecast will be converted to a monthly average excluding the backlog. [**58**] [**57**]
- The forecast for the number of wheel sets requiring a light repair is currently 90% of the total. For this comparison it will be taken as 80% of the total, to be conservative.
- The current practice (at TRE Salt River) is to replace the bearings with each repair on any wheel set. With any under-coach wheel reprofiling, the bearings are not replaced. Potential safety requirements will be considered for different bearing replacement frequency requirements. The maximum number of times that a tyred wheel can be reprofiled is six. The longest frequency is thus 1:5, where the wheel set requires a new tyre in every fifth year and thus will also receive new bearings. [**34**]
- The lifting jack price is supplied by Yale Engineering Products, with the cost calculated for the installation of an entire row of jacks to service a 14-coach train set. [**59**]
- The calculations do not include the tax and depreciation implications.

Average Annual ROI comparison	U2000-400	MOBITURN®2
Operating cost/wheel set	R2 604	R2 604
TRE (Salt River) avg. cost	R5 510	R5 510
Saving/wheel set	R2 906	R2 906
Annual light demand (number of wheel sets)	1701	1701
Annual light demand with 1 in 2 bearing replacement	855	855
Annual light demand with 1 in 3 bearing replacement	1140	1140
Annual light demand with 1 in 4 bearing replacement	1283	1283
Annual light demand with 1 in 5 bearing replacement	1368	1368
Annual cost saving (1 in 2)	R2 484 536	R2 484 536
Annual cost saving (1 in 3)	R3 312 715	R3 312 715
Annual cost saving (1 in 4)	R3 728 257	R3 728 257
Annual cost saving (1 in 5)	R3 975 258	R3 975 258
Investment cost	R15 740 000	R36 140 478
ROI (1 in 2)	15,78%	6,87%
ROI (1 in 3)	21,05%	9,17%
ROI (1 in 4)	23,69%	10,32%
ROI (1 in 5)	25,26%	11,00%

Table 21 ROI comparison of the U 2000-400 and the MOBITURN®2

From table 21, it is apparent that the frequency with which the bearings need to be changed has a significant impact on the RIO. It is also apparent that both the U2000-400 and the MOBITURN®2 have significant spare capacity. The current forecast only takes the Metrorail demand into consideration. The Shoshaloza Meyl requirements would also have an impact and improve the ROI. Furthermore, the MOBITURN®2 system is mobile and can be moved by road or rail transport to any other Metrorail region. Due to the significant spare capacity, a further evaluation considers the ROI of sharing one MOBITURN®2 unit between the Western Cape, Eastern Cape and Kwa-Zulu Natal regions. The following extra considerations are required for the sharing of the MOBITURN®2 between the three regions:

- The transport and setup time between the regions is taken as one working week.
- Each region needs its own set of lifting jacks.
- The cost of transport is estimated at R 100 000, with 3 trips per annum. [**31**]
- In order to meet the total potential demands, the MOBITURN® would need to work extra shifts on occasion. (This is possible, as it is currently only scheduled to work one 8-hour shift per day)

Average Annual ROI for Sharing one MOBITURN®2	MOBITURN®2
Production capacity/year	2748
Purchase cost	R13 920 000
Installation costs	R0
Shunting unit/ lifting jacks	R57 138 372
Total	R71 058 372
Operating cost/wheel set	R2 604
TRE (Salt River) avg. cost	R5 510
Saving/wheel set	R2 906
Annual light demand for all three regions	2934
Annual light demand with 1 in 2 bearing replacement	1467
Annual light demand with 1 in 3 bearing replacement	1956
Annual light demand with 1 in 4 bearing replacement	2201
Annual light demand with 1 in 5 bearing replacement	2347
Annual cost saving (1 in 2)	R4 262 941
Annual cost saving (1 in 3)	R5 683 921
Annual cost saving (1 in 4)	R6 395 864
Annual cost saving (1 in 5)	R6 820 124
Transport @ 3 trips per annum	R300 000
Investment cost	R71 058 372
ROI (1 in 2)	5,58%
ROI (1 in 3)	7,58%
ROI (1 in 4)	8,58%
ROI (1 in 5)	9,18%

Table 22 ROI evaluation of sharing one MOBITURN®2 unit between three regions

From table 21 and table 22, it is evident that the best alternative would be to acquire an under-floor lathe system, as it has the best ROI figure. The figures used have been conservative and still clearly show that the investment in an under-floor lathe would have a maximum payback period of under 7 years. The following knock-on benefits would be achieved over and above the direct financial benefits.

- The indirect competition would ensure competitive prices from TRE, specifically for light reconditioning work.
- The pressure on TRE would be decreased, allowing for faster turn-around times for heavy and medium reconditions.
- At worst, the number of lifts in the lifting row due to wheels would decrease by 40% and so, fewer spare coaches would be required.
- The float of spare wheel sets could also be reduced, which would free up capital and would be a first step toward Lean Maintenance.

- As the new fleet arrives from 2015 onwards, both the U2000-400 and the MOBITURN®2 would still be able to handle the increased demand, as they could operate two extra shifts per day, effectively tripling their capacity.

6.2.3.3 Investigation Conclusions

From table 21, the minimum annual saving for the Western Cape region is about R 2,4 million, with a maximum payback period of less than 7 years.

Based on these findings, a full investigation into insourcing light wheel reprofiling capability should be performed. The cost acquiring a mobile system is most impacted by the lifting jack consideration. If not all the lifting jacks are required in each region and if Metrorail were able to negotiate a discount based on the number of lifting jacks required, the mobile under-coach system could be reinvestigated.

6.3 Metrorail shedding cycle analysis

This chapter deals with the high level application of some of the principles that have been derived from, and based on, the policy. It is divided in to five main parts. The first, section 6.3.1, deals with an investigation into the Should-Be state of the scheduled maintenance cycle (shedding cycle) along with some history of the development of the cycle. The Should-Be state describes how the current system is intended to operate along with some details thereof. Section 6.3.2 deals with the AS-IS state of the current Metrorail cycle in the Western Cape, wherein the effects of and reasons for the current state are also elaborated on. The next two sections deal with the proposed solutions and recommendations. Thus, section 6.3.3 deals with short-term solutions/recommendations and section 6.3.4 the long-term solutions/recommendations. The final section provides the conclusion for this chapter and discusses further investigations and research that should be considered for the shedding cycle.

6.3.1 The Should-Be model of the current scheduled maintenance cycle

From chapter 3 the basic history and current state of PAM can be summarized as follows: Most of the current Should-Be situations are based on the 1998 SARCC-Metrorail main agreement. This main agreement itself is primarily based on the OEM specifications and manuals. The most recent rolling stock acquisition took place in the mid-1980s. The current Should-Be scheduled maintenance cycle (shedding cycle) is derived from those OEM specifications and manuals and on the Railway Safety Regulator regulations. The consolidation of these parts resulted in the shedding cycle being based on 18 000km intervals between each of the full scheduled maintenance events. This 18 000km cycle should be applied throughout the entire sphere of Metrorail operations and is thus used in every region except the Port Elizabeth-East London region due to their different operating conditions. [**10**] [**3**]

In Chapter 3 it was also mentioned that this 18 000km cycle was converted into an 8-week cycle with three different levels of maintenance and inspections meant to take place within that cycle at 2-week intervals. These three levels are the Passenger Safety and Comfort scheduled maintenance cycle (PS&C), the Intermediate scheduled maintenance cycle (Intermediate Shedding), and the Full scheduled maintenance cycle (Full Shedding). Each of these three shedding cycle forms its own sub-section in this thesis. The three shedding cycles share a common platform on which they are based and this common platform is discussed in the next sub-section.

6.3.1.1 Generic scheduled maintenance procedures

In order to identify trends and patterns, train sets operate on specific routes. In the Western Cape these routes or lines are the North, South and Central lines. To complement this, the work teams that perform the scheduled maintenance are also separated and designated to specific lines. Because of this, the work teams become familiar with the train sets that they are working on and the process should, theoretically, become more efficient. [**32**]

Shedding operations normally take place between 00:00 and 04:00. During this time, no train operations occur. Not all train sets operate until midnight, so if they have been scheduled to receive shedding that night, maintenance can start earlier. All train sets are required to meet the peak demand, which correlates to normal rush hour. In order reach at the required stations for morning rush hour, the train sets need to be available by 04:00. All scheduled maintenance is planned to occur within this four-hour window and each shedding team has been trained to perform all three different shedding cycles. This should improve the knowledge and experience that each team has regarding each particular train set. It also lessens the likelihood that the same maintenance task is done twice. [**36**]

On each occasion where a piece of equipment no longer performs and/nor meets specification, it is called a fault. The work teams record these faults and assign pre-determined fault codes. All faults that are detected during the shedding procedure are, where possible, corrected within the four-hour shedding window. Should the magnitude of the fault prevent the correction from taking place, the train set is stopped and is either replaced by a reserve set or enters service late. [**32**]

The specific tasks that are performed in each cycle are set out in the 1998 SARCC-Metrorail main agreement. The relevant sections of the agreement are included in Appendix H. Not all scheduled maintenance tasks need to be performed every two weeks; some only occur every four or even eight weeks. This forms the basis for the three shedding cycles. The actions that need to take place every two weeks form part of the PS&C. Every fourth week, the PS&C tasks are augmented by extra tasks that make up the remainder of Intermediate Shedding. Similarly, Full Shedding is made up of all the PS&C and Intermediate Shedding tasks, plus the extra specific tasks that only need be performed every 8 weeks. The detailed checklists of each of these three cycles can be found in the Appendix I. Table 23 lists the eight systems of a train set and each system is checked during each scheduled maintenance cycle. [**60**] [**61**] [**62**]

Train set systems	
System	System description
High Tension Traction System	This system includes the pantograph and all high- and low tension equipment and wiring.
Electric Control System	The electrical control system involves all the electrical components as well as all other forms of control of the electric system.
Body	The two body systems are similar, but this system check focuses primarily on the piping and wiring related components including lights, hooters and wipers.
Body (Vehicle Building)	The vehicle body system focuses specifically on the interior and exterior appearance mainly from a comfort point of view.
Auxiliary Equipment	Auxiliary equipment includes the compressors, exhausters and motors.
Coach Compressed Air System	The steering and support includes the bogie, the suspension, wheels and other elements of the undercarriage.
Brake system	The brake system is used to slow or stop the train, with special focus on the brake pads/blocks and the vacuum system that operates the brakes.

Table 23 Summary of the systems on a train set [36]

The average cost of a PS&C, Intermediate and Full Shed are unavailable due to Metrorail not knowing what the cost breakdown is for each of the three sheds. [**32**]

6.3.2 The current scheduled maintenance procedure

Under the best conditions, the two-week cycle is applied across all three operational corridors, namely North, South and Central. The lengths of these three lines vary greatly and most of the train sets, specifically those on the Central and South lines, do not achieve their bi-weekly kilometres. Due to the various challenges, in particular the acute shortage of reprofiled wheel sets, the operating conditions as well as the scheduled maintenance operations have changed.

Ideally, the Western Cape region operates 85 train sets per day, with an average length of 11 coaches. At the height of the difficulties, only 72 train sets were operational, of these 42 were shortened train sets. [**32**] The direct and indirect effects have been mentioned throughout this document, but are now collectively summarized below:

- In some cases, entire train sets have had to be moved on to a different line/route

- Train sets were broken up and added to other train sets
- The added coaches took on the shedding cycle of the adopting train set
- In order to minimize the impact, the number of trips per operational train set increased.
- Not all stopped coaches and sets could be securely parked and many of these coaches and sets have since been vandalised.

Since then, the situation has improved. At the time of writing, the number of operational train sets has increased to 82, with only 11 of these being shortened trains. The improvement has been achieved by outsourcing the reconditioning of many coaches, and even whole trains sets. These activities have been funded by Head Office and do not form part of the budget of the Western Cape region. Furthermore, in order to prevent over-utilisation of operational train sets, train sets that reach their allocated travel distance before their scheduled maintenance cycle, are parked until their planned shedding. [**36**]

From the RCM analysis into the wheel set maintenance system, it was discovered that there are currently no bearing-related PM tasks being performed during any of the shedding procedures. This was reconfirmed when the three shedding procedure checklists were analysed.

6.3.3 Short-term recommendations for the scheduled maintenance procedure

Both the short-term and long-term recommendations are intended to function within the existing budget. The financial boost from Head Office, to get the required number of train sets into service, is seen as a temporary measure. Once normal operations have been resumed, each region will need to perform within its set budget. Due to the lack of accurate financial information regarding each cycle, only general recommendations could be made. [**32**]

6.3.3.1 Recommendation 1: Conversion from time-based shedding to usage-based shedding

The original 2-week cycle of the shedding program was developed based on the number of kilometres a train set covers. The average usage rate in 1998 was such that this translated to an approximate 2-week cycle. Since 1998 the circumstances have changed. The first short-term recommendation is as follows: Without changing any of the safety levels or procedures, the first short-term solution is to change the static, 2-week cycle into a dynamic, usage-based cycle. The 18 000km interval would still remain the same, but it would no longer be restricted to an 8-week cycle.

This will, however, require more planning and administration. When the initial 18 000km cycle was developed in 1998, the use of personal computers had not yet become commonplace. With current technology and generic programs like Microsoft Excel, it would be possible to coordinate such a change. Metrorail has its own maintenance management system called FMMS, with which it could be possible to accommodate such a change.

Even if all 85 train sets remain operational, the current demand exceeds the supply with regard to urban rail travel. [**28**] This recommendation would allow for an increase in the number of scheduled trains.

6.3.3.2 Recommendation 2: Hybridising the shedding cycle

From the investigation into PAM systems and the proposed policy, it is apparent that the most suitable PAM strategy will always be a hybrid strategy. It will involve all the primary types of maintenance tasks. By applying the idea of hybridisation to the shedding cycles, the following recommendation has been developed, taking into consideration the applicability of split train sets that have been combined with other sets.

In the event that train sets are split and combined with other sets, the current procedure is to let the added coaches adopt the existing sets' shedding cycle. This results in either under- or over maintenance. Consider figure 21, with train set A and train set B. Every train set receives shedding every two weeks within its specific 8-week cycle. In week 0, the set has received a Full Shed, in week 2 it receives a PS&C, in week 4 an Intermediate Shed, in week 6 the second PS&C and in week 8 a Full Shed again. Train set A finds itself in week 6 and train set B in week 2. In order to visualize the cycle, the cost of each cycle is represented on the y-axis, thus the shortest bar is a PS&C and the tallest a Full Shed.

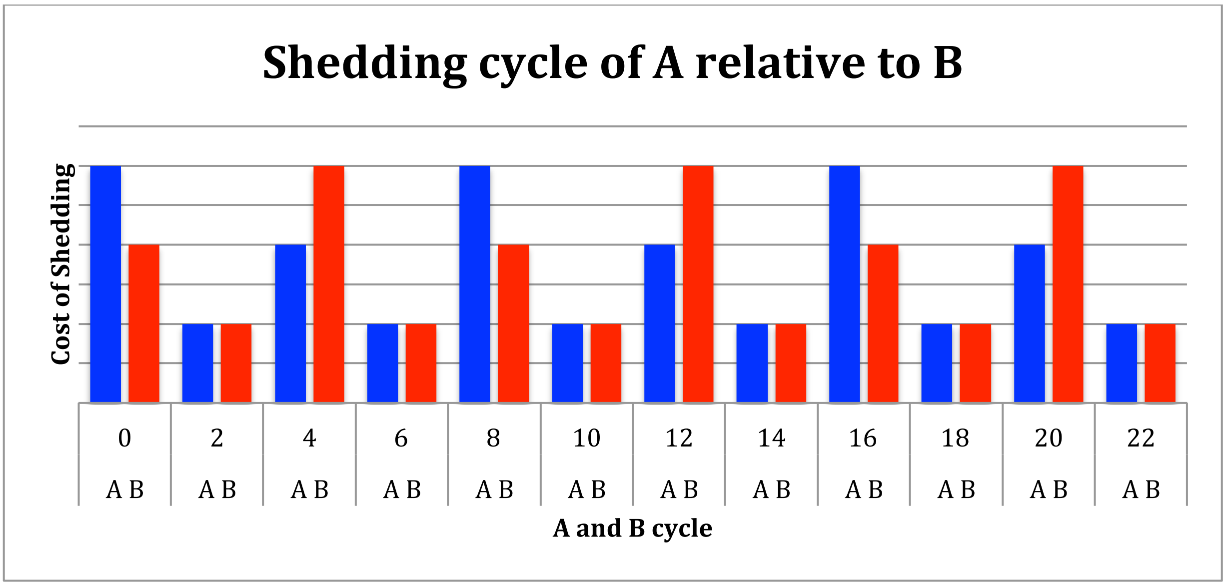

Figure 21 A graphic representation of the shedding cycle of two train sets

If the majority of A is stopped in week six, with two coaches not stopped and B has only two coaches that need to be stopped, then the remaining coaches from A would join B. Within the

current system, A would be artificially placed with B in week 2, thus being six weeks late and over-utilised before its next Full Shed. This creates a significant safety concern.
Alternately set A could only have two coaches stopped and B could have only two coaches not stopped (with eight still operational). If the remainder of B joins A, then the B coaches would receive a Full Shed within 4 weeks of their previous Full Shed and thus be over-maintained. The over-maintenance causes a cost increase.

The first aspect of the recommendation is that the coaches within their train set are maintained within their own cycle. Thus, in two weeks time, within the newly formed combination set, the coaches from A receive their required Full Shed and the coaches from B their required Intermediate Shed. In so doing, the new set receives a hybrid shed consisting of, partly, a Full Shed and partly an Intermediate Shed. This way, initially, the coaches are neither under- nor over-maintained.

Ideally, each entire set should receive the same scheduled maintenance. The second part of the recommendation is: when the cycles of a combined set are synchronised, they should be synchronised the next time the majority of the set receives a Full Shed. This way the safety would never be compromised and the cost impact is minimized. In the example of set A and B: if, in the new combined set, the two A coaches receive a Full Shed when the B coaches receive their Full Shed, the A coaches will have received two Full Sheds in the space of four weeks, instead of in the usual eight. The effect of this is that only two coaches are over-maintained. If the B coaches would be synchronised to the A coaches, when the A coaches receive a Full Shed, eight coaches would be over-maintained, instead of only two.

From this the general recommendation is a follows:
In the event that a train set needs to be split and combined with the remainder of a second train set, then the coaches in the new train set should receive their intended scheduled maintenance and be recombined when the financial impact is lowest. The lowest financial impact for safely synchronising a new train set can be achieved by synchronising the minority of the train set to the majority, when the would-be cost difference between the two sheds is at its lowest. From a safety perspective, synchronising should only be done through over-maintenance.

6.3.4 Long-term recommendation for the scheduled maintenance procedure

Due to the changes in utilization, age and technology that have occurred since 1998, when the 18 000km cycle was developed, and since the mid 1980s, when the last new train sets and thus OEM manuals were acquired, the current 18 000km cycle is out of date. The recommendation is that the 18 000km cycle be reviewed, specifically by applying an RCM analysis to the systems within a train set.

The benefit of an RCM analysis has been evidenced through its application to wheel sets, where a shortfall in the current shedding checklist was identified and significant, potential financial savings were identified, through investigating one of the items of interest. An RCM analysis supports and meets the requirements set forth by the proposed RAM policy.

7 Conclusion

This chapter serves as the conclusion of the research project. General and specific conclusions are drawn, followed by a discussion of the contributions of this research to theory and practise. An evaluation, with regard to the objectives and goals, is done, along with recommendations and possible further research work.

7.1 General Conclusions

The need for PAM strategies and plans to be guided and bound by a framework in order to align with the requirements of an organisation and its employees, physical assets and customers, has been highlighted throughout this thesis. To achieve this alignment and guidance, organisations need a PAM policy that facilitates the selection and development of PAM strategies and plans.

From literature it became evident that there can be no entire generic PAM policy that can be directly be adopted by different organisations. A PAM policy needs to be specific to the situation and context of an organisation. To address this need, a generic PAM policy statement was therefore developed (called RAM, or Requirement-based Asset Management), with the specific focus on facilitating the alignment of PAM with the needs, both present and future, of an organisation.

The suitability of RAM, as a generic PAM policy statement, was investigated by evaluating it against the high level requirements of a specific organisation. The vision, mission and values of PRASA, the Passenger Rail Agency of South Africa, were used to evaluate the suitability of RAM.

In order to discover the applicability of RAM, a proposed strategic roadmap was developed. The roadmap consists of two phases. The purpose of the first would be to lay the foundations of a "world-class" PAM system by getting the fundamental principles of PAM right. Phase 2 would then build on this foundation by looking at future best practices such as IRIS and PAS 55. Phase 2 was only developed as a concept, as it would be shaped by phase 1 and its outcomes. The implementation of phase 1 was validated through application in the following three different areas.

The initial RCM analysis required a Pareto style analysis and resulted in the discovery of the Top 7. The investigation into the Top 7 brought forth the full application of RCM into the case of wheel set maintenance. Based on these results, the final area of application, the shedding cycle, was chosen. These three areas allowed a linked investigation into three different areas of the organisation. The Top 7 investigation created the opportunity to evaluate the impact of the policy derived roadmap on managerial and planning functions. This in turn led to an investigation into the maintenance of the specific sub-system of wheel sets, followed by a general, broader maintenance investigation into shedding cycles.

7.2 Specific Conclusions

Through the application of the RAM derived roadmap in the three areas, the following findings and results were achieved:

Top 7:

- A lack of vertical communication exists between the Rolling Stock Planning Department and Head Office, with insufficient feedback concerning the Top 7.
- The Top 7 only highlight the primary contributors to in-service faults that cause delays or cancelled trips.
- From a once-off comparison of different contributors to cancelled train trips it was discovered that the Top 7 can contribute as little as 14% to this number.
- From the once-off comparison the significance of the wheel set shortage was highlighted.

Wheel set maintenance:

- In most cases, the existing PM activities are the best suited to the current situation.
- The exception is bearing-related PM activities. The lack of inspections is disconcerting and especially significant in light of train sets operating with reprofiled wheels from the under-floor system in Saldanha. This concern will become more pronounced if Metrorail installs its own under-coach systems.
- The problem with supply from TRE was highlighted.
- Financially sound alternatives where presented.

Scheduled maintenance cycle:

- The lack of bearing-related PM tasks was confirmed.
- Specific problems with regard to the shortening of train sets were highlighted.
- A safe mitigation was developed, with the lowest possible financial impact.
- Further improvement suggestions were made and discussed in section 7.5.

Based on these summarized results, the objectives and goals are now considered.

7.3 Evaluation in Terms of Objectives

This section deals with the evaluation of the objectives and goals, whose development was based on the objectives, as they were set out in the introduction. The structure of this thesis was built around the specified goals, which have all been achieved. The list below specifies each goal and relevant sections:

- *A comprehensive literature study on PAM policies and PAM strategies, in order to establish the connection between the policy and the strategies that could be derived from it. This includes the following:*
    - *Research on what the current best practises are with regard to PAM*
    - *Research into the potential future trends in PAM*

  Chapter 2 forms a significant part of this thesis and is solely dedicated to addressing the first goal, with the first sub-point being covered in section 2.1 and 2.2. The last two sections of 2.2 investigate some future trends.

- *A comprehensive study into the current PAM system at Metrorail, PRASA's primary subsidiary, and the state of PAM within Metrorail.*
  The discussion of the state of PAM in Metrorail forms the content of chapter 3.

- *Developing the generic policy statement and a proposed strategy roadmap derived from the policy.*
  Chapters 4 and 5 cover the policy statement and proposed roadmap respectively, with chapter 5 going further, by comparing RAM directly with the higher-level objectives of PRASA in order to identify any shortcomings of the generic policy.

- *The application of the derivatives from the PAM policy in three different but linked areas within Metrorail.*
  The largest part of this thesis, chapters 6 to 6.3, is concerned with the application of different elements of the policy in order to establish the applicability and suitability thereof.

- *Evaluating the application of the PAM policy derivatives, in order to establish the suitability of the PAM policy by implication.*
  The final chapter (7) of this thesis addresses the evaluation of the objectives and goals.

Due to the achievement of the aforementioned goals, the objectives of this thesis are now discussed.

Objective1: *To develop a generic physical asset management policy statement that can be used to derive a suitable physical asset management policy for PRASA and its subsidiaries, specifically Metrorail.*

A generic policy statement was developed and selectively applied in Metrorail. The three specific areas of application are the Top 7, wheel set maintenance and the shedding cycle. The generic policy statement has also been presented to PRASA, who would like to develop it further into a complete policy in 2012.

Objective 2: *The focused application of the generic policy statement in PRASA and Metrorail, its subsidiary, through the proposed strategies and tasks, will show its applicability and suitability.*

Through the focused application of the three linked, but different, areas within the Rolling Stock department of Metrorail, significant potential savings and improvements were identified. These improvements and potential savings showed both the applicability and suitability of the policy-derived roadmap, and by deduction, the generic policy itself.

7.4 Contribution to Theory and Practice

The development of the generic policy and the successful application of its derivatives have contributed to the field of asset management by providing a basis for the development of a PAM policy for an organisation. Due to its generic nature, the policy statement is not limited to any specific industry and can be applied to any organisation with PAM needs.

The diverse portfolio that PRASA manages highlights the significance of its plans to use RAM and further shows the breadth of the applicability of RAM.

7.5 Recommendations and Further Work

The first and foremost recommendation is to use RAM to develop a PAM policy for PRASA. Following this, a full investigation should be made into the proposed roadmap that was developed to evaluate the applicability of the generic policy. The following recommendations are specific to the three areas of application that were used to validate the policy statement, through the derived roadmap.

Top 7:

- Communication needs to be improved between Head Office and the planning department, in order to maximise the impact that the monthly Top 7 has.
- The Top 7 should be expanded or repeated specifically for workshop related faults that cause train trip cancellations.

- Tying in with the recommendation of the roadmap investigation, any RCM study should start with either of the Top 7.

Wheel maintenance:

- Bearing maintenance needs to be re-evaluated, specifically in light of the train sets that are operating with wheel sets that were reprofiled in Saldanha and with the possibility of expanding and acquiring its own under-coach reprofiling systems for Metrorail.
- A full investigation into the alternatives for Metrorail to perform their own under-coach maintenance should be performed.

Scheduled maintenance cycle:

- Priority needs to be given to safety. Recombined train sets cannot simply follow the maintenance cycle of the adopting train set. The recommendation is to keep the different coaches on their separate shedding cycles until they can be suitably synchronised.
- The synchronisation of the shedding cycle should occur as follows: The minority of the train set needs to be over-maintained to synchronise with the majority of the coaches of the train set. This should occur when the cost difference between the actual cycles is smallest.

8 References

[1] 7th Annual State of Logistics Survey for South Africa 2010. Pretoria: CSIR; 2010.

[2] Lombard M, Cameron B, Mokonyama M, Shaw A. Report on Trends in Passenger Transport in South Africa. Midrand: Development Bank of South Africa; 2007.

[3] Mtimkulu D. [E-mail communication,]. Stellenbosch; 2011.

[4] PAS 55-1:2008. London: British Standards Institute; 2008.

[5] Maister D. Strategy and the Fat Smoker. Boston: The Spangle Press; 2005.

[6] Mann L. Maintenance Management. Lexington: D.C. Heath and Company; 1982.

[7] Patton JD. Preventive Maintenance. Research Triangle Park: Instrument Society of America; 1983.

[8] Smith AM. Reliability-Centered Maintenance. New York: McGraw-Hill; 1993.

[9] Jardine AKS, Tsang AHC. Maintenance, Replacement, and Reliability - Theory and Applications. Oxford: Taylor & Francis Group; 2006.

[10] SARCC-Metrorail Main Agreement. Pretoria: South African Rail Commuter Corporation; 1998.

[11] PAS 55-2:2008. London: British Standards Institute; 2008.

[12] Asset Insights. [Online] [s.a.] [access 2011]; Available: http://d1072223.domain.com/Bulletins/B_Maintenance_Policy.html

[13] Definition of a maintenance policy [Online] [s.a.] [access 2011, September]; Available: http://www.kwaliteg.co.za/maintenance/maintenance%20policy.htm

[14] Waeyenbergh G, Pintelon L. Maintenance concept development: A case study. International Journal of production economics 2004; 89:395-405.

[15] Willmott P, McCarthy D. TPM - A Route to World-Class Performance. Oxford: Butterworth-Heinemann; 2005.

[16] Smith R, Hawkins B. Lean Maintenance. Oxford: Elsivier; 2004.

[17] Levitt J. Complete Guide to Preventive and Predictive Maintenance. New York: Industrial Press; 2003.

[18] Scrimshire D. IRIS – Global business management system for the railway industry supply chain [Online] 2006 [access 2011, September]; Available: http://www.bsigroup.com/upload/MS-Images/MS-Documents/IRIS_Technical_Article.pdf

[19] Tsang AHC. Strategic dimensions of maintenance management. Journal of Quality in Maintenance Engineering 2002; 8(1):7-39.

[20] Chase RB, Jacobs FR, Aquilano NJ. Operations Management for Competitive Advantage. New York: McGraw-Hill/Irwin; 2006.

[21] About the Passenger Rail Association of South Africa [Online] [s.a.] [access 2011, January]; Available: http://prasa.com/About.aspx

[22] Mtimkulu D. Approaching Implementation of Maintenance Management System Holistically in a Rolling Stock Maintenance Environment for University of Stellenbosch. [unpublished dissertation]. Stellenbosch; 2006.

[23] Mtimkulu D. 3D-Maintenance Application Management Guide - Functional Maintenance Policy for Department of Engineering Services of PRASA. Braamfontein.

[24] About Metrorail [Online] [s.a.] [access 2011, February]; Available: http://www.metrorail.co.za/About.html

[25] Panchoo MS. [E-mail communication]. Cape Town; 2011.

[26] About Transnet Rail Engineering [Online] [s.a.] [access 2011, October]; Available: http://www.transnet.net/Divisions/RailEngg.aspx

[27] Transnet Rail Engineering [Online] [s.a.] [access 2011, October]; Available: http://www.transwerk.co.za/(S(wbte4y45qsfshdnzqzhjfs55))/Default.aspx

[28] Montana L. Open Letter to parliament [Online] 2010, February [access: 2011, September] Available: http://www.prasa.com//PressRelease20100207.aspx

[29] Dirks S. Wheel forecast as at October 2011. Unpublished internal report. Cape Town; 2011.

[30] Conradie P. [Personal communication]. Stellenbosch; 2011.

[31] Mnisii WK. [E-mail communication] Cape Town; 2011.

[32] Van den Bank G. [E-mail communication]. Cape Town; 2011.

[33] Moving South Africa. Department of Transport. Government report 1997.

[34] Dirks S. [E-mail communication] Cape Town 2011.

[35] Railway Safety Regulator safety documents. [Online] [s.a.] [access: 2011, October]; Available: http://www.rsr.org.za/RSR/railway_safety_documents.php?pag=safety

[36] Southgate C. [E-mail communication]. Cape Town: 2011.

[37] Lord Kelvin. Electrical Units of Measurement. Physics Letter A 1883;1.

[38] Definitions. [Online] [s.a.] [access 2011]; Available: http://www.businessdictionary.com/

[39] Anderson B. Industrial benchmarking for competitive advantage. Human Systems Management. 1999;18(3).

[40] Network Rail. Asset Management Policy. London 2011.

[41] Network Rail. Assat Management Strategy. London 2011.

[42] Ferrovie dello Stato. Maintaining the New FS Rolling Stock. Florence 2001.

[43] RailCorp. Spoil Wagon Specific Maintenance Policy. 2010ESR 0017.

[44] RailCorp. Container Wagon Specific Maintenance Policy. 2010 ESR 0012.

[45] RialCorp. Base R1/R2 Wagon Maintenance Policy. 2010 ESR 0011.

[46] Muruvan TFP, Feng S, Dunn WA, Henning RC, The development of a benchmarking tool for monitoring progress towards sustainable transportation in New Zealand. Transport

Policy 2011; 18: 480-488.

[47] Mini Business Goal Alignment. Cape Town: Competitive Dynamics International; 2011

[48] Fourie CJ. [Personal communication]. Stellenbosch; 2011.

[49] Van den Bank G. Rolling Stock Top 5 Faults. Unpublished internal report. Cape Town; 2011

[50] Van Rensburg M. [E-mail communication]. Cape Town; 2011.

[51] FMMS generated documents. [Offline electronic database]; 2011

[52] Mgidi NC. 2011/12 Coach Wheels Pricing Schedule. Internal Document; Johannesburg: TRE; 2011 April 21.

[53] Büdenbender W. [Personal communication]. Erkelenz; 2010 August 24.

[54] Welty G. When bearings fail… - railroad cars. CBS Resource Library Web site. [Online] [1991] [access 2011, October]; Available: http://findarticles.com/p/articles/mi_m1215/is_n12_v192/ai_11711593/pg_5/?tag=content;col1

[55] Matzan E. Detecting Premature Bearing Failure. Machinery Lubrication 2007;5.

[56] Kosa F. [E-mail communication] Johannesburg; 2011.

[57] Budget Quotation Under-floor Wheel set Lathe. [Official quotation]. Hegenscheidt-MFD; 2011, April 5

[58] Budget Quotation Mobile Wheel set Reprofiling System. [Official quotation]. Hegenscheidt-MFD; 2011, April 5

[59] Kruger R, Quotation for a set of Yale Coach Lifting Jacks. Johannesburg: Yale Engineering Products; 2011.

[60] Gabryk T. B Shed - (Inter) 5M2/5M2A/10M Electrical Fitter Check Sheet. Johannesburg: PRASA; 2010, January 19.

[61] Gabryk T. A Shed - (PS&C) 5M2/5M2A Electrical Fitter Check Sheet. Johannesburg: PRASA; 2010, January 19.

[62] Gabryk T. C Shed (Full Shed) - Consolidated Electrical Fitter Check. Johannesburg; PRASA; 2011 September 5.

[63] Humphreys P, McIvor R, Huang G. An expert system for evaluating the make or buy decision. Computers & Industrial Engineering 2002;42: 567-585.

[64] McIvor R, Humphreys P. A case-based reasoning approach to the make or buy decision. Integrated Manufacturing Systems 2000;11(5): 295-310.

Appendix A:

RCM Matrices and Decision Trees

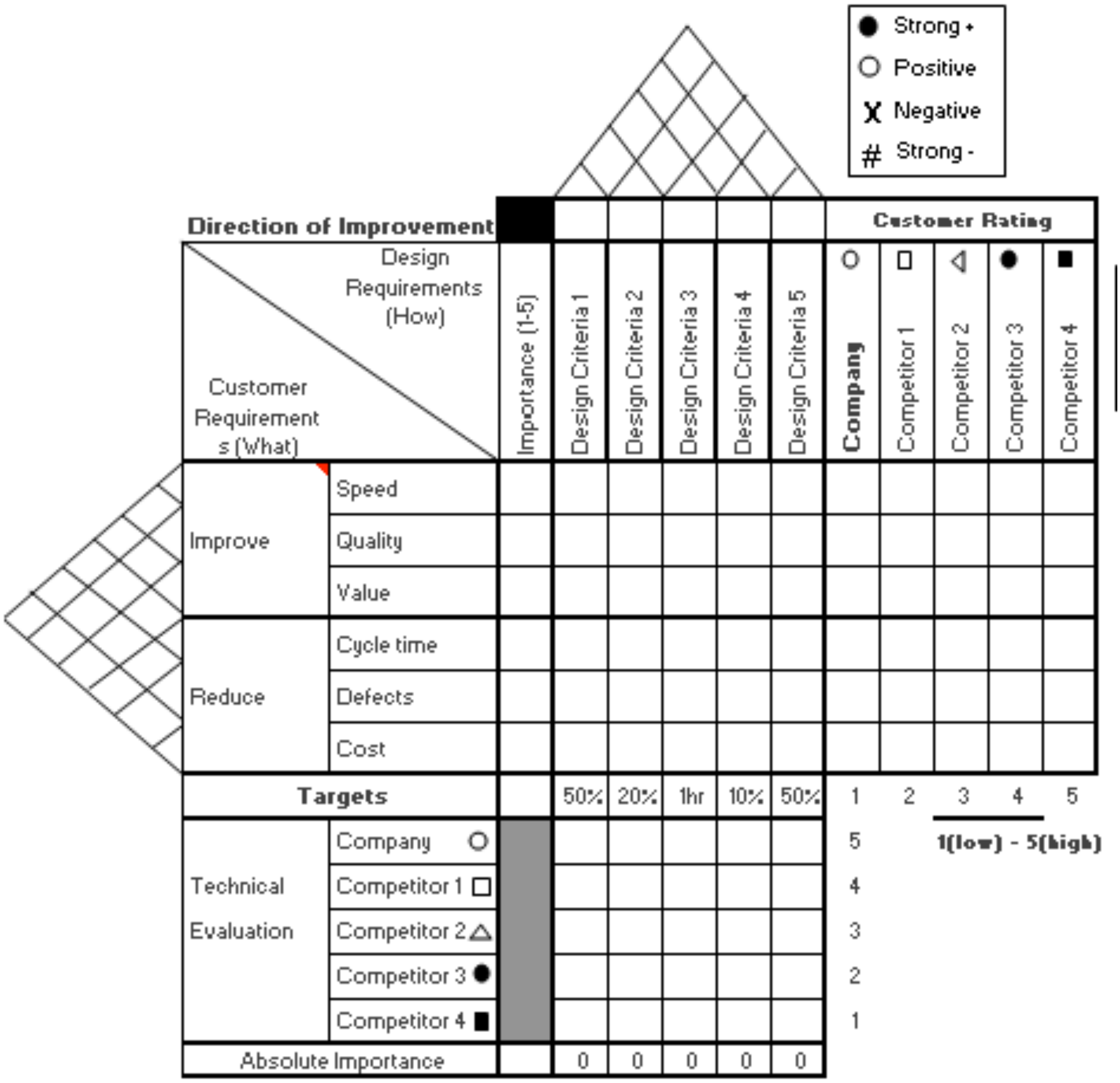

Figure A1 House of Quality Matrix, which has been used to develop the Equipment Failure Matrix [20]

RCM—Systems Analysis Process

Step 4: Functions/functional failures		
Information: Equipment–functional failure matrix	Rev no.:	Date:
Plant:	Plant ID:	
System name:	System ID:	
Analysts:		

No.	Equipment (or component) name	Functional failures								

Figure A2 Equipment Failure Matrix [8]

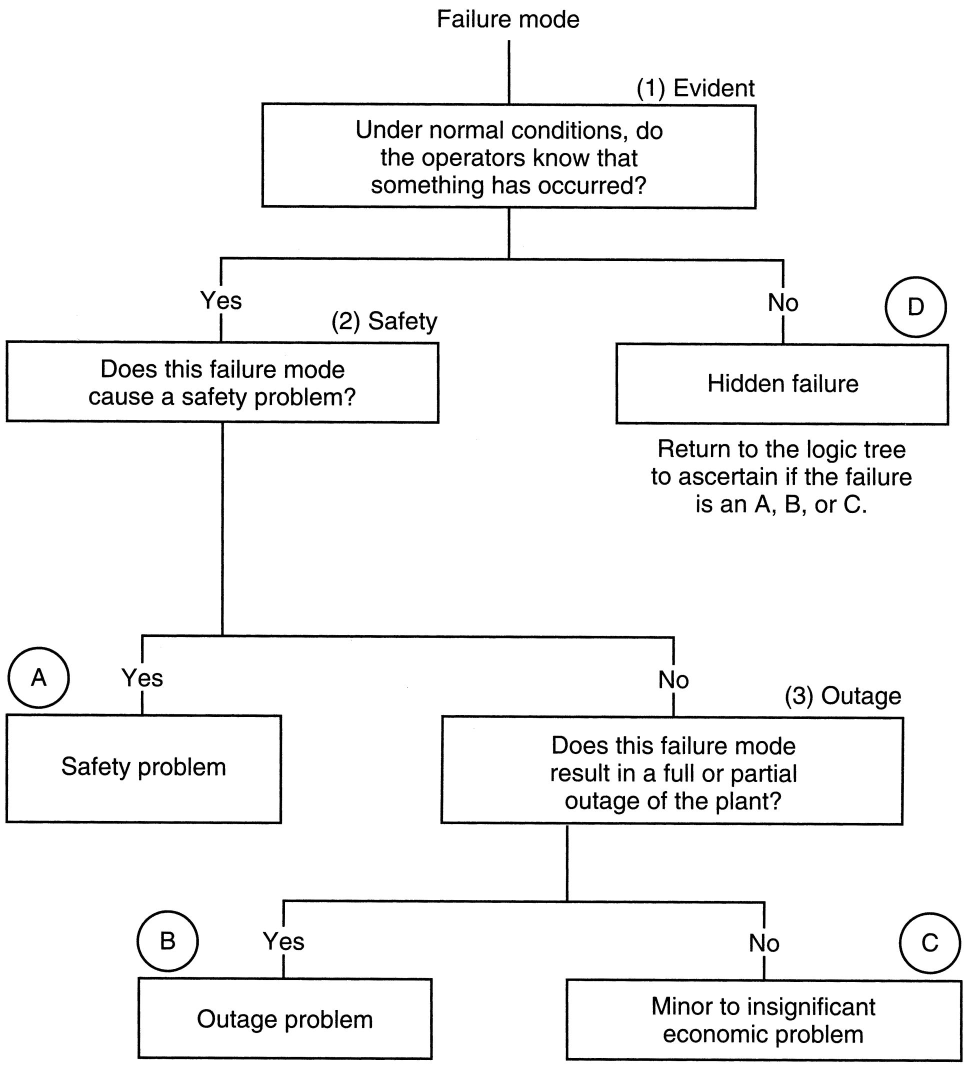

Figure A3 Logic (Decision) Tree flow chart, used in the RCM analysis. [8]

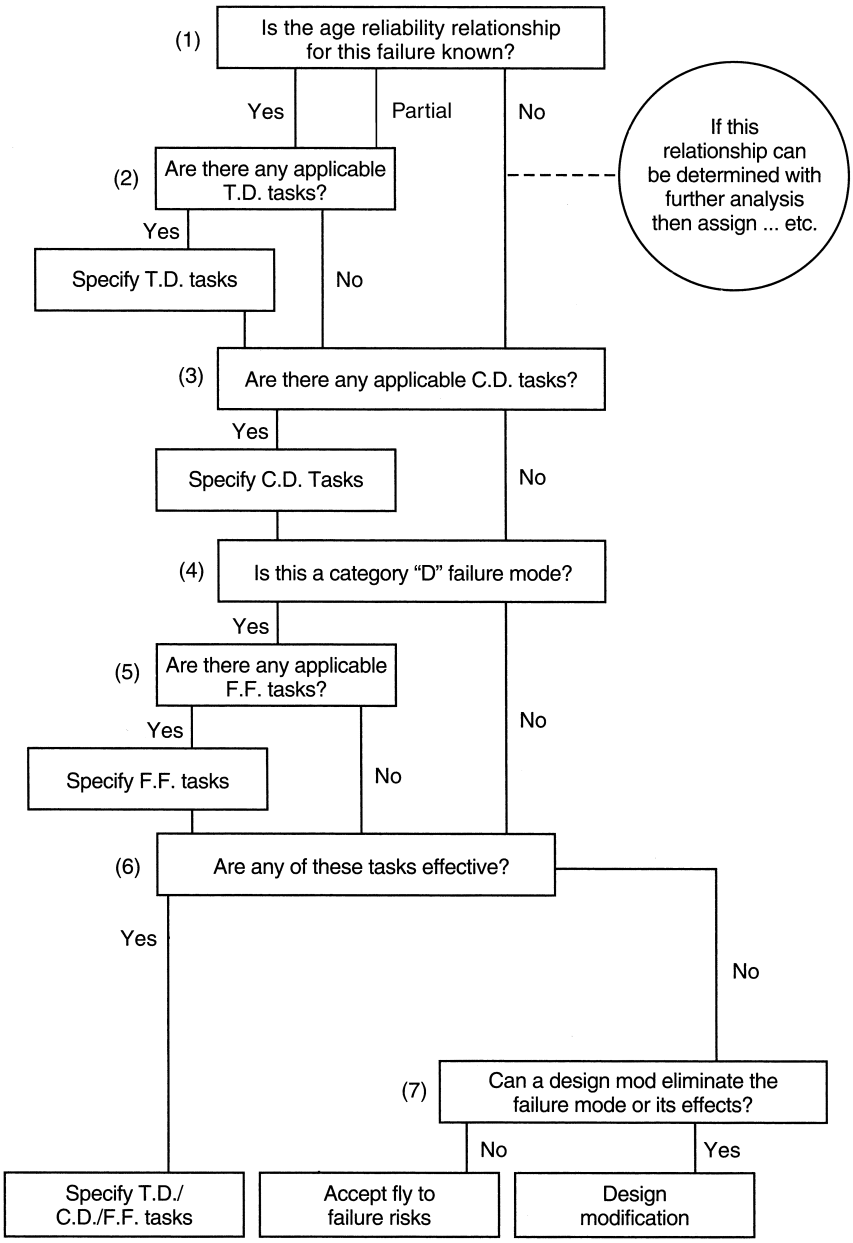

Figure A4 Task Selection Decision Tree, used in the RCM analysis [8]

Appendix B:

IRIS Tables

List Of significant IRIS additions to ISO 9001:2000	
Clause	Clause title
4.3	Knowledge management
4.4	Management of multi sites projects
5.5.4	Customer relationship management
7.3	Tender management
7.4	Project management
7.5	Design and development
7.5.8	First article inspection
7.6	Configuration management
7.7.3	Supply chain management
7.8	Production and service provision
7.9	Commissioning/Customer service
7.10	RAMS/LCC
7.11	Control of monitoring and measuring devices
8.2.4	Monitoring and measuring of product
8.4	Control of nonconforming process

Table B1 List of significant additions that IRIS makes to ISO 9001:2000 [18]

List of the 13 documented procedures mandated by IRIS	
Clause	Clause title
4.1	Transfer or outsourcing of activities
4.2.3	Control of documents
4.2.4	Control of records
6.1	Provision of resources
6.2.2.2	Training
7.5.6	Design and development validation (documentation of test procedures)
7.5.8	First article inspection
7.8.2.3	Maintenance for equipment and tools
7.10	RAMS
8.2.2	Internal audits
8.3	Control of nonconforming product
8.6.2	Corrective actions
8.6.3	Preventative actions

Table B2 List of 13 documented procedures mandated by IRIS [18]

List of the 19 processes mandated by IRIS	
Clause	Clause title
4.1	Cost management
4.2.3	Control of customer documents
7.1	Planning of product realization
7.3	Tender management
7.4	Project management or new product development
7.4.5	Project management - quality management
7.4.8	Project management - risk and opportunity management
7.4.9.1	Project management - change management
7.4.9.2	Project management - obsolescence management
7.5	Design and development
7.6	Configuration management
7.7.1	Purchasing process
7.8.2.2	Control of production process changes
7.8.3	Validation of processes for production and service provision
7.9	Commissioning/Customer service
7.10	LCC
7.11	Control of monitoring and measuring devices
8.1	Monitoring, measurement, analysis and improvement
8.4	Control of nonconforming process

Table B3 List of 19 processes mandated by IRIS [18]

Appendix C:

PRASA and Metrorail Legislative Mandates

Legislative Mandate of PRASA [21]

Legal Succession Act

PRASA as an arm of the National Department of Transport, the shareholder, primary focus is to focus on the mandate as contained the Legal Succession to the South Africa Transport Services ("SATS")
Act of 1989 as amended in November 2008.

The main object and the main business of the Agency are to—

- ensure that, at the request of the Department of Transport, rail commuter services are provided within, to and from the Republic in the public interest; and
- provide, in consultation with the Department of Transport, for long haul passenger rail and bus services within, to and from the Republic in terms of the principles set out in section 4 of the National Land Transport Transition Act, 2000 (Act No. 22 of 2000).

The second object and secondary business of PRASA is that the Agency, PRASA shall generate income from the exploitation of assets acquired by it.

A further requirement is that, in carrying out its object and business, PRASA shall have due regard to key government social, economic and transport policy objectives.

Vision

To be South Africa's Number One Public Transport Operator.

Two fundamental principles underpin the vision:

- Integration – PRASA should facilitate integrating individuals and communities, enabling a better quality of life through access to socio-economic opportunities.
- Mobility Solutions – PRASA should connect individuals and communities through the provision of public transport solutions that are founded on an integrated network of mobility routes.

Mission

To Strive for Service Excellence, Innovation and Modal Integration for Sustainable Public Transport Solutions

The mission reflects three key intentions:

- Service excellence – superior performance that is safe, reliable and affordable, provide a dignified travel experience that makes a lasting impression, and builds brand loyalty – both internally (employees) and externally (customers) – that adds benefit to the passenger.
- Sustainability - a focus on sustainable development in business that considers not just the financial 'bottom line' of prosperity and profit, but also environmental quality and social equity.
- Modal Integration – reframing the basis of business delivery, favouring innovation, seamless integration and partnerships

Values

The values that will guide PRASA, underpinning the performance ethos of the organization have been derived via Group wide workshops involving all units and all levels of staff. The premise of the values is to deliver service excellence, productive staff and business growth. The values are:

- **Fairness and Integrity**
  Treating our customers and our colleagues the same as we would like to be treated.
- **Service Excellence**
  Provide the kind of service that ensures that our customer leaves with a smile.
- **Performance Driven**
  Developing the ability to venture into new breakthrough areas of opportunity whilst offering quality products to our customers.
- **Safety**
  Ensuring our customers and colleagues enjoy their journey and arrive safely and refreshed.
- **Communication**
  Sharing information with our customers and colleagues in an open and honest way

- **Teamwork**

  Working together with our customers to achieve a common goal and recognising each other's worth.

Legislative Mandate of Metrorail [24]

Metrorail - South Africa's biggest and preferred provider of passenger and commuter rail services. Owned by PRASA, PRASA is a State Owned Enterprise (SOE) under the auspices of the Department of Transport.

Our primary mandate in accordance with the Legal Succession Act to SATS Act (Act 9 of 1989) is to ensure that, at the request of the National Department of Transport or any sphere of government, rail commuter services are provided in the public interest, and to promote rail as the primary mode of mass commuter transportation.
Metrorail has the custodianship of all commuter and passenger rail assets such as land in and around stations, infrastructure and rolling stock.
PRASA operates commuter rail services through Metrorail, transporting over 1,7 million passengers on weekdays in major Metropolitans made out of Five Regions Namely:

- Wits
- Cape Town
- Tshwane
- Durban
- Eastern Cape

The five Regions combined occupy about 478 stations with a fleet of over 270 train sets making up to 3100 coaches with each coach carrying more than 100 people.

Our core business of moving people safely resonated by our Metrorail Theme "Getting South Africa to work" effectively covers 2 400 Kilometres of track throughout South Africa. With effect from the 1st of April 2008 SARCC will run and operate long-distance passenger rail through Shosholoza Meyl to effect the 2004 Cabinet decision of creating a single passenger rail entity.

We provide rail services to meet the countries needs of affordable public transport. We are committed to the provision of safety and comfort to the millions of commuters who rely on our service for mobility and access.

Our subsidiary, Intersite Property Solutions is responsible to provide total property solutions through management, building, upgrading and revamping of stations throughout the entire network.

Our strategy is about:

Transforming and positioning passenger rail to form the basis of Integrated Mass rapid Public Transport Networks in South Africa.

Vision

Enhanced mobility as the gateway to accessible socio-economic opportunities and a shared future.

Two fundamental principles underpin the vision:

- **Accessibility:** PRASA should facilitate access – be a gateway - to a better quality of life by enabling individuals and communities to access socio-economic opportunities.
- **Mobility:** PRASA should connect individuals and communities through an integrated network of mobility routes.

Mission

Sustainable transport solutions through service excellence, innovation and modal integration

PRASA's mission reflects four key intentions:

- **Service excellence -** superior performance that is safe, reliable and affordable, and which makes a lasting impression by actively building brand loyalty – both internally (employees) and externally (customers) – ultimately adding benefit to the passenger.
- **Sustainability -** a triple bottom line focus on sustainable development that considers not only financial profit, but also environmental quality and social equity.
- **Mobility solutions -** reframing the basis of business delivery to favour innovation, integration and partnerships
- **Integration -** safe, seamless and dignified travel experiences across all modes of public transport

Appendix D:

List of Fault Codes

AA	ADJUSTMENT OUT
AB	AIR COCK DEFECTIVE
AC	AIR HOSE PERRISHED / MISSING
AD	AIR PIPE BLOCKED
AE	AIR PIPE BURST / LEAKING
AF	AIR PIPES HOLED / RUSTED
AG	AIR VALVE DEFECTIVE
AH	ANTENNA DEFECTIVE
AJ	ARC BARRIERS WORN / BURNT
AK	ARC CHUTE WORN / BURNT / DEFECTIVE
AL	ARCHORN FLASHED / BURNT / BROKEN
AM	ARMATURE DEFECTIVE
AN	AUXILIARY TRANSFORMER DEFECTIVE

BA	BALANCING GEAR DEFECTIVE(
BB	BEARING FAILURE
BC	BELL DOME MISSING / LOOSE
BD	BELL PLUNGER STICKY / ADJUSTMENT
BE	BELLOWS TORN
BF	BLOW OUT COIL O/C / FLASHED / SBT
BG	BODY BURNT
BH	BODY COLLISION DAMAGED
BJ	BODY HOLED
BK	BODY PAINT FADED
BL	BODY RUSTED
BM	BOGIE CRACKED / BENT
BN	BRAKE BLOCK WORN
BO	BRAKE GEAR ADJUSTMENT
BP	BRAKE SHOES CUT
BQ	BREAST PLATE WORN
BR	BRUSH BOX INSULATOR BROKEN / FLASHED
BS	BRUSH BOX WORN / BURNT
BT	BRUSHES WORN / CHIPPED / STICKY
BU	BURST BINDER
CA	CABLE EARTHED
CB	CABLE SHORTED
CC	CABLES / WIRING BURNT / OC / LOOSE

CD	CALIBRATION
CE	CAPACITOR DEFECTIVE
CF	CARBONS WORN
CG	CENTRIFUGAL SWITCH TRIPPED
CH	CENTRIFUGAL SWITCH WORN / BENT
CI	CIRCUIT BREAKER BURNT / O/C
CJ	COACH VANDALISED
CK	COIL O/C, SHORTED
CL	COMMUTATOR WORN
CM	CONNECTION LOOSE / BURNT
CN	CONTACT DRUM BURNT / WORN
CO	CONTACT GAPS INCORRECT
CP	CONTACT PRESSURE LOW / HIGH
CQ	CONTACTS GLAZED / BURNT / WORN / BROKEN
CR	CONTROL BOX WORN
CS	CONTROL VALVE DEFECTIVE
CT	COUPLER WORN
CU	COVER / CLIP MISSING / BROKEN(Hot Suspension)
CV	COWCATHER DAMAGED
CW	CRACKED TYRE
CX	CUT
CY	CUT OUT SWITCH FLASHED OVER

DA	DAMAGED
DB	DAMAGED / MISSING
DC	DEFECTIVE
DD	DISC WORN
DE	DOOR ANTI TIPPERS WORN / MISSING
DF	DOOR CABLES / BELT OFF / MISSING
DG	DOOR FOREIGN OBJECT UNDER DOOR
DH	DOOR GUIDES BENT / MISSING / LOOSE
DJ	DOOR HANDLE BROKEN / MISSING
DK	DOOR INCORRECT HEIGHT
DL	DOOR LOCK MISSING / DAMAGED
DM	DOOR MOTOR DEFECTICE
DN	DOOR OFF RAIL
DO	DOOR RAIL LOOSE / BROKEN

DP	DOOR RUBBERS MISSING / WORN
DQ	DOOR STOPS MISSING / DAMAGED
DR	DOOR TAILPIECE MISSING / DAMAGED
DS	DOOR TROLLEY LOOSE / BROKEN
DT	DRAIN VALVE DEFECTIVE

EA	ELECTRONICS DEFECTIVE
EB	ENCAPSULATED COIL CRACKED / FLASHED
EC	EXCESSIVE DIRT - EXTERIOR
ED	EXT. CABLES /CONNECTIONS / BOXES DEFECTIVE

FA	FILTER BLOCKED
FB	FIRE EXTINGUISHER DATE EXPIRED
FC	FIRE EXTINGUISHER MISSING / EMPTY
FD	FLATS
FE	FLEXIBLE TUBE HOLDER MISSING / BROKEN
FG	FLUORESCENT TUBES BLOWN
FH	FULCRUM PLATE BENT / DAMAGED
FJ	FULCRUM RUSTED
FK	FUSE BLOWN
FL	FUSE BOX COVER MISSING
FM	FUSE CARRIER FLASHED
FN	FUSE CLIPS BURNT
FO	FLOOR STRUCTURE DAMAGED
FP	FLOOR COVERING DAMAGED

GA	GEARCASE LEAKING / DAMAGED
GB	GEARWHEEL / RESILIENT BUSHES
GC	GLOBES BLOWN / MISSING
GD	GUIDES WORN

HA	HEATER ELEMENT O/C
HB	HEATER MISSING
HC	HIGH MICA
HD	HOOTER DISC DEFECTIVE
HE	HORN GUIDE LINERS WORN

Figure D1 Is the first half of the list a Fault Codes [44]

IA	IDLER / WIPER ARM BENT
IB	INSULATION FLASHED / BURNT / EARTHED
IC	INSULATORS FLASHED / DIRTY / BROKEN
ID	INT. CABLES / FIELDS / INTERPOLES DEFECTIVE
IE	INTERLOCKS DEFECTIVE
IF	INVERTER DEFECTIVE

KA	KNUCKLE WORN

LA	LAMPHOLDER MISSING / BROKEN
LB	LEAKING
LC	LIGHT LENS MISSING / BROKEN
LD	LINKS / BLADES SEIZED / BURNT / GLAZED
LE	LOCKING MECHANISM DEFECTIVE
LF	LOOSE TYRE
LG	LOW MEGGER READING
LH	LUBRICATION DEFICIENCY

MA	MAGNET VALVE STICKY
MB	MICRO SWITCH DEFECTIVE

NA	NECK RING WORN
NB	NUMBER PADS TORN

OA	OIL LEVEL LOW
OB	OUTPUT VOLTAGE HIGH / LOW

PA	PANTO SKATE DAMAGED
PB	PANTO SKATE STRIPS WORN / BROKEN
PC	PIN / BUSHES WORN
PD	PINION KEY SHEARED
PE	PINION WORN
PF	PISTON LEAKING / SLUGGISH
PG	POPPIT VALVE WORN / STICKY / LEAKING
PH	PULL ROD WORN / BROKEN
PJ	PUSH BUTTON CONTACTS BURNT

RA	RECEPTACLE COVER MISSING
RB	RECEPTACLE DAMAGED
RC	RECEPTACLE INSULATOR FLASHED / CRACKED
RD	RECTIFIER DIODE DEFECTIVE
RE	REDUCING VALVE DEFECTIVE
RF	RELAY STUCK
RG	RELAY TRIPPED
RH	RELEASE WIRE BROKEN
RJ	RESISTOR O/C
RK	ROLLER RINGS WORN
RL	ROLLER WORN

SA	SAFETY VALVE DEFECTIVE
SB	SCROLLS TORN
SC	SEALED BEAM BLOWN / BROKEN
SD	SEALS WORN / MISSING / DAMAGED
SE	SECURING BELT DAMAGED
SF	SEIZED
SG	SHADE MISSING / BROKEN
SH	SHUNT STRAP FRAYED / BURNT / FLASHED
SI	SIDE SCREEN / COVERS DAMAGED / MISSING
SJ	SIREN DEFECTIVE
SK	SIREN SWITCH DEFECTIVE
SL	SKIDDED WHEELS
SM	SLIP RINGS WORN / FLATS
SN	SPEED SLOW / FAST
SO	SPEEDO AMPLIFIER DEFECTIVE
SP	SPEEDO CABLE O/C
SQ	SPEEDO GENERATOR DEFECTIVE
SR	SPEEDO PROBE DEFECTIVE
SS	SPINDLES WORN / DAMAGED
ST	SPLIT PINS MISSING / WORN
SU	SPRING PLATE DAMAGED
SV	SPRING WEAK / MISSING
SW	STICKY
SX	SUPPORT BARS FLASHED / EARTHED
SY	SWITCH BURNT / DEFECTIVE
SZ	SWITCH IN CUT OUT POSITION

TA	TEST / EXAMINATION
TB	THIN FLANGE / TYRE DOWN TO GAUGE
TC	TUBES BENT / BROKEN
TD	TYRE CHIPPED
TS	GROOVE

UA	UNEVEN BRUSH TRACK

VA	VACUUM HOSE LEAKING
VB	VACUUM HOSE PERRISHED / MISSING / HOLED
VC	VACUUM HOSE SEAL MISSING
VD	VALVE / PIPE BLOCKED
VE	VALVE LEAKING
VF	VALVE STICKY / DIRTY
VG	VEE RING FLASHED
VH	VESTIBULE STEMS WORN

WA	WEAK
WB	WEAR & TEAR
WC	WINDOW BROKEN / STUCK / MISSING
WD	WINDOW FRAME RUSTED
WE	WINDOW GLASS SCRATCHED
WF	WIPER MOTOR DEFECTIVE
WG	WORN
WH	WRONG CONNECT

YA	YOKE WORN

Figure D2 The second half of the list of Fault Codes [44]

Appendix E:

TRE Wheel Maintenance Processes and Price Lists, Wheel Set Drawings and Wheel Set Forecasts

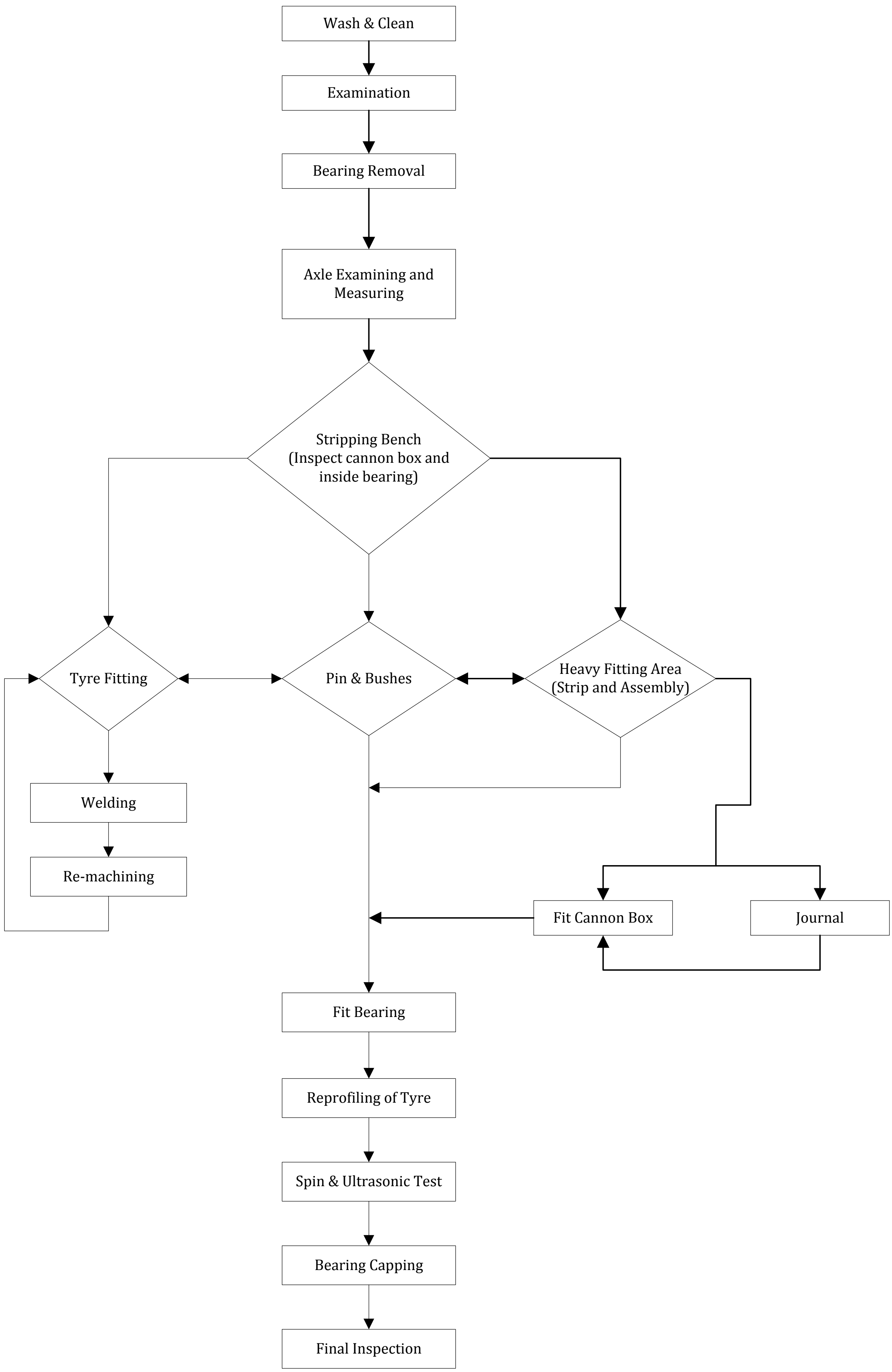

Figure E1 The process flow chart of the Cannon Box Wheel Set maintenance at TRE [34]

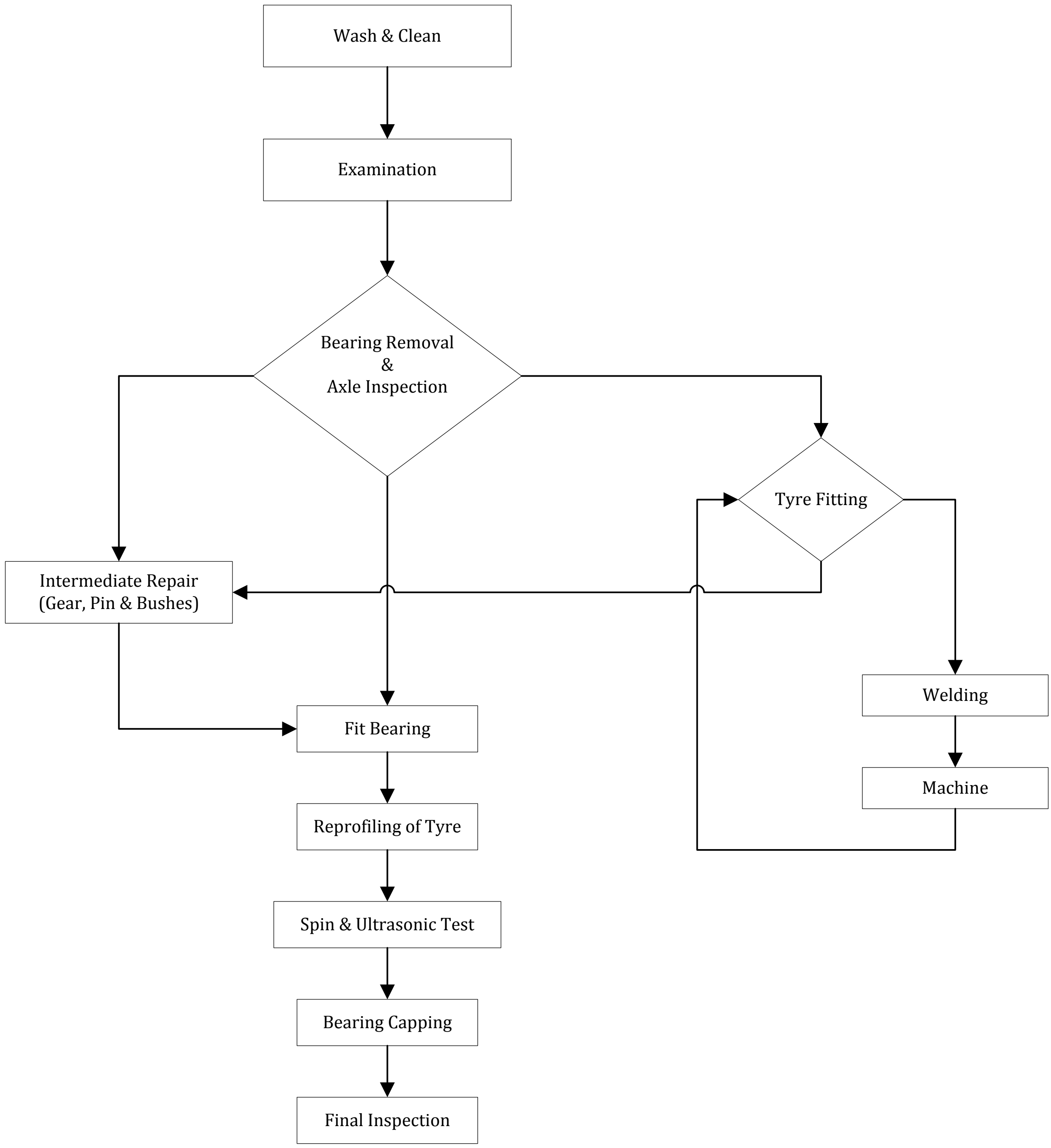

Figure E2 The process flow chart of the Oil-Sleeve Wheel Set maintenance at TRE [34]

5M2A Motor Coach Wheel Oil-sleeve		2009/10 FINAL PRICE			
		Prices	Typical valuation classes		
#	Task Description		Light	Med	Heavy
1	Examine	R 1 543,00	R 1 543,00	R 1 543,00	R 1 543,00
2	Renew axle	R 20 247,00			R 20 247,00
3a	Reclaimable centres	R 3 478,00			R 3 478,00
3b	Retyre	R 20 717,00		R 20 717,00	R 20 717,00
4	Reprofile	R 633,00	R 633,00	R 633,00	R 633,00
5	C-Repair 5M2A	R 546,00			
6	Intermediate Repair	R 1 535,00		R 1 535,00	R 1 535,00
7a	Renew gear	R 95 700,00			
7b	Fit recon gear	R 13 438,00			R 13 438,00
8	Fit pins and bushes	R 4 390,00	R 4 390,00	R 4 390,00	R 4 390,00
9	Convert to APD (incl adaptor)	R 2 141,00			
10	Dalic bearing seat (one end)	R 1 182,00			
11	Turn and roll axle inner	R 773,00			
12a	Fit Recon bearing	R 3 450,00	R 3 450,00	R 3 450,00	
12b	Renew bearing	R 6 518,00			R 6 518,00
13	Spin test wheel	R 111,00			
			R 10 016,00	R 32 268,00	R 72 499,00

Table E1 The pricing structure for the different classes of maintenance for the Oil-Sleeve Wheel Set [52]

5M2AR Motor Coach Wheel Cannon box		2009/10 FINAL PRICE				
		Prices	Typical valuation classes			
#	Task Description		Light	Med	Heavy	New
1	Examine	R 1 543,00	R 1 543,00	R 1 543,00	R 1 543,00	R 1 543,00
2	Renew axle	R 20 247,00			R 20 247,00	R 20 247,00
3a	Reclaimable centres	R 3 478,00			R 3 478,00	
3b	Renew centres	R 60 632,00				R 60 632,00
3c	Retyre	R 20 717,00		R 20 717,00	R 20 717,00	
4	Reprofile	R 633,00	R 633,00	R 633,00	R 633,00	R 633,00
5	C-Repair APF	R 546,00				
6a	C-Repair cannon box	R 771,00	R 771,00	R 771,00		
6b	Renew cannon box	R 24 398,00			R 24 398,00	R 24 398,00
6c	Dalic plate cannon box	R 7 829,00		R 7 829,00		
7	Intermediate Repair	R 7 299,00		R 7 299,00	R 7 299,00	R 7 299,00
8a	Renew gear	R 95 700,00				R 95 700,00
8b	Fit recon gear	R 13 438,00			R 13 438,00	
9	Fit pins and bushes	R 4 389,00	R 4 389,00	R 4 389,00	R 4 389,00	R 4 389,00
10	Convert to APD (incl adaptor)	R 1 896,00				
11	Dalic bearing seat (one end)	R 1 182,00				
12	Turn and roll axle inner	R 773,00				
13a	Fit Recon bearing	R 3 450,00	R 3 450,00	R 3 450,00		
13b	Renew bearing	R 6 518,00			R 6 518,00	R 6 518,00
14	Spin test wheel	R 111,00				
			R 10 786,00	R 46 631,00	R 102 660,00	R 221 359,00

Table E2 The pricing structure for the different classes of maintenance for the Cannon Box Wheel Set [52]

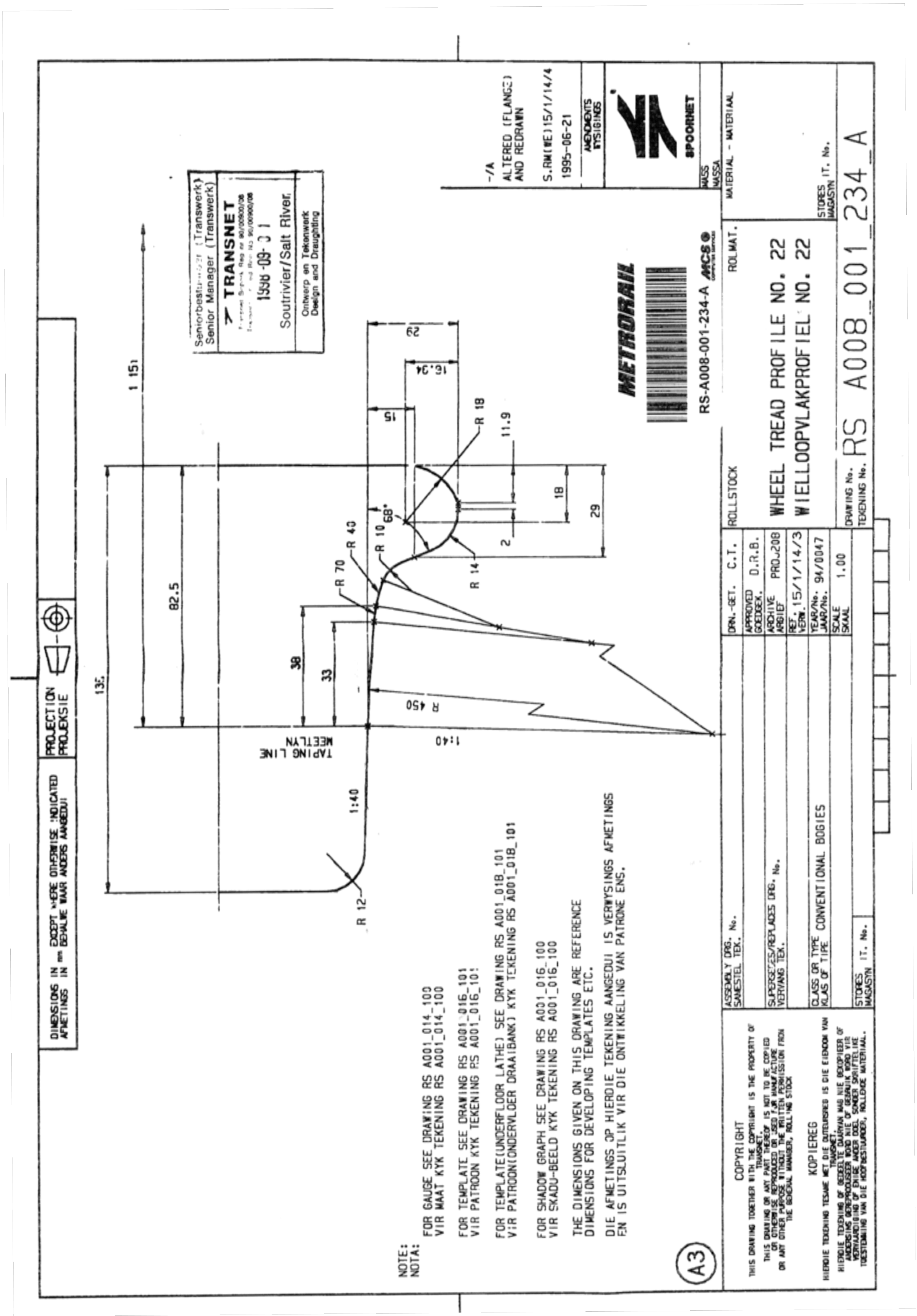

Figure E3 Engineering drawing of the cross section of a wheel profile [33]

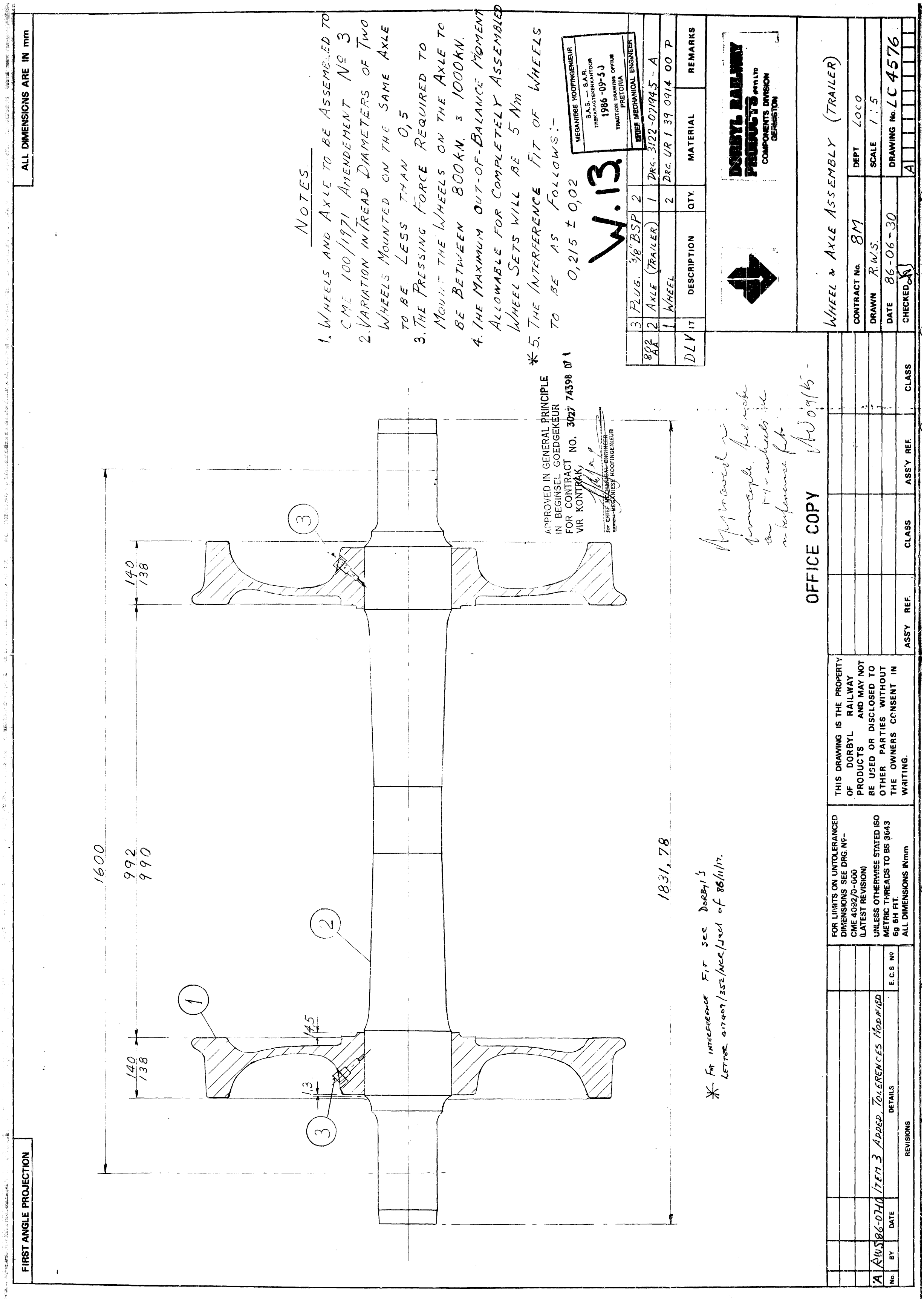

Figure E4 Assembly engineering drawing of a Plain Trailer wheel set

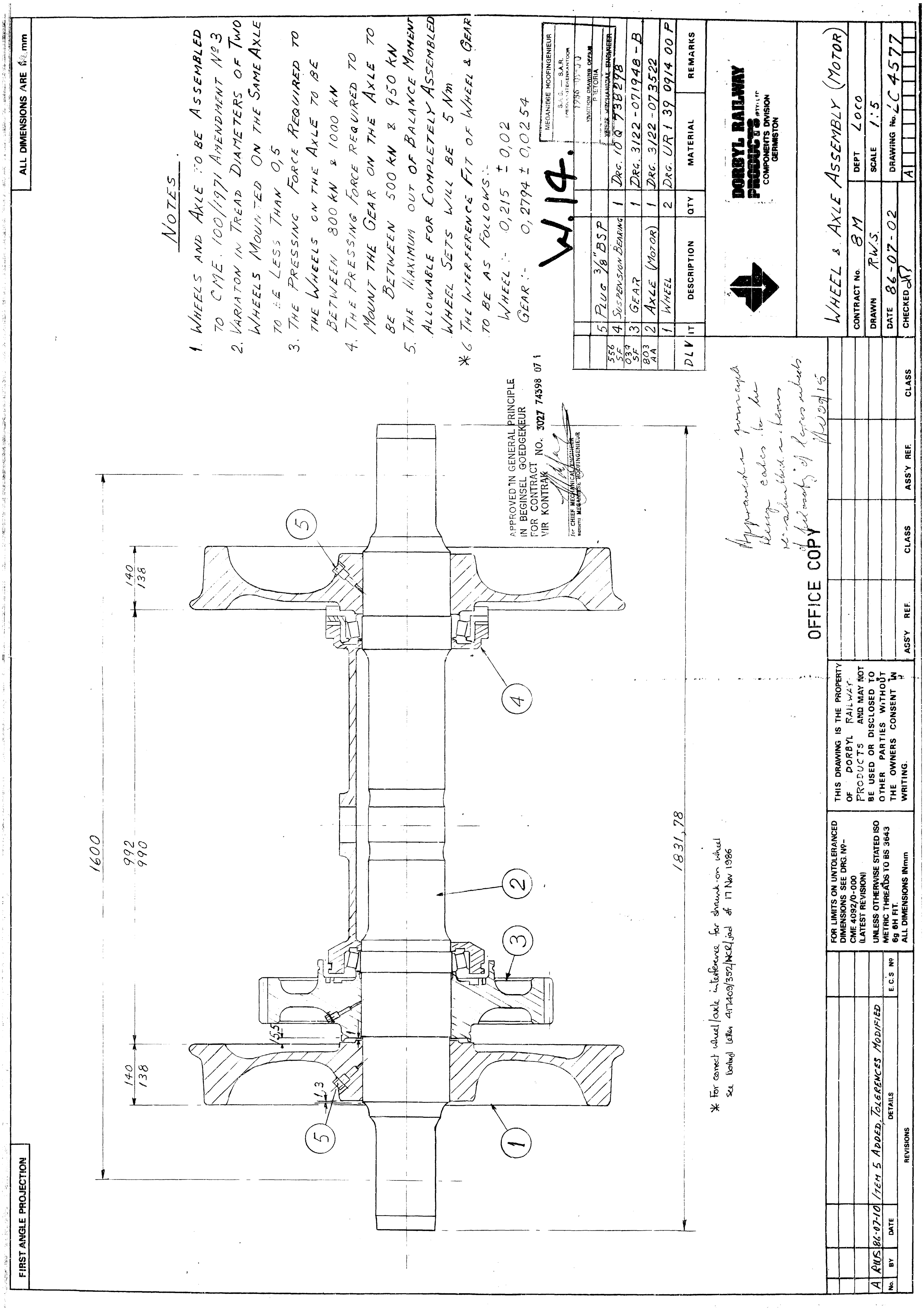

Figure E5 Assembly engineering drawing of a Motor Coach wheel set [33]

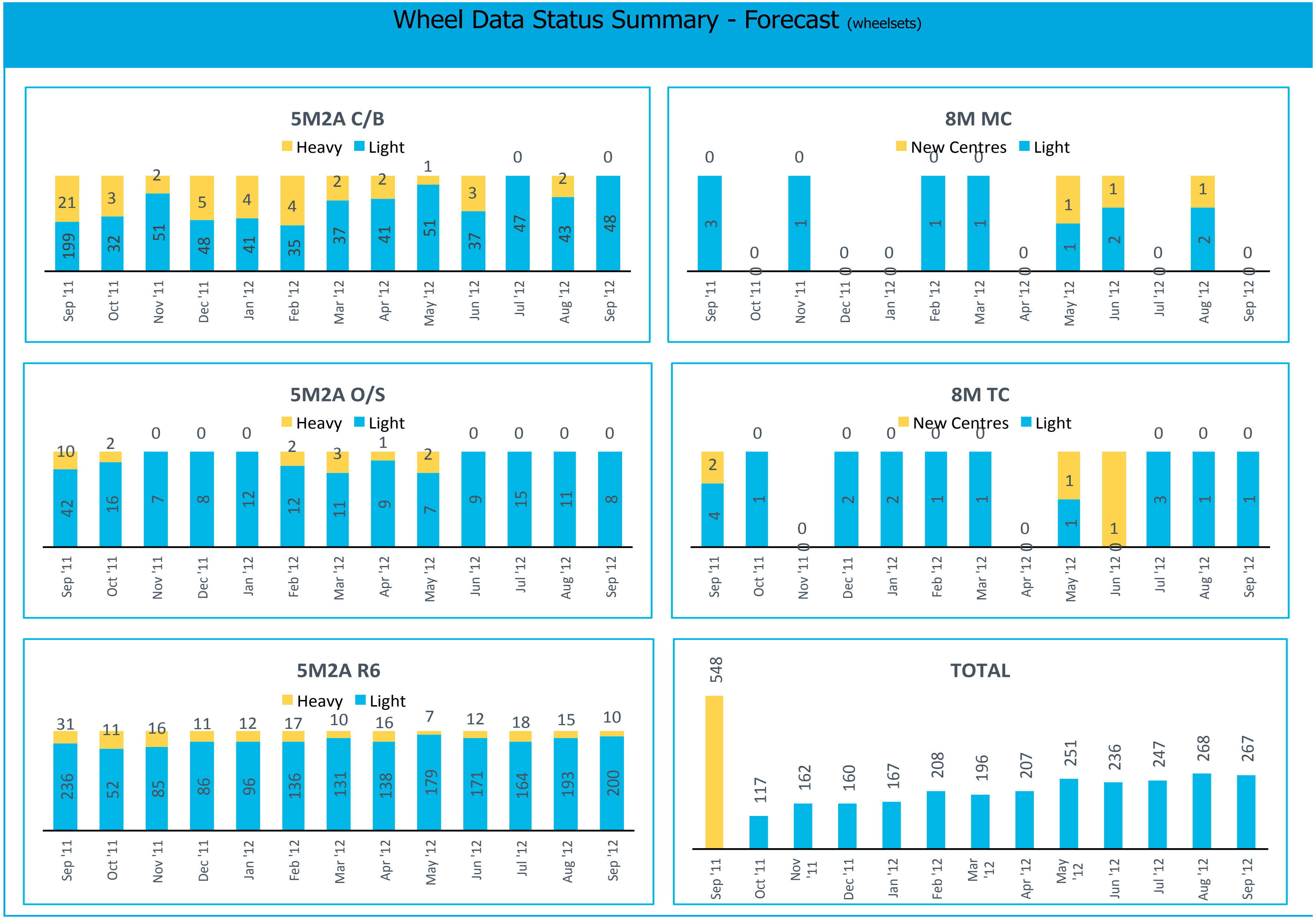

Figure E6 Distribution of wheel set maintenance forecast per type of wheel set [29]

Appendix F:

RCM Wheel Set Analysis Tables

Failure Mode and Effects Analysis

Failure mode	Failure cause	Local effect	Effect to system	Effect to
Wheels				
Functional Failure: 1.1.1 - Lifts/Bounces off track				
.01 - Becomes loose	.01.01 - Incorrect fitting	Tyre comes loose, wheel travels unevenly, leaves track	Coach derails	Train s
	.01.02 - Damage during operation			
.02 - Ring cracks	.02.01 - Impact damage	Tyre comes loose, wheel travels unevenly, leaves track	Coach derails	Train s
	.02.02 - Material flaw			
See FF 1.3.3				
See FF 2.2.2				
See FF 3.1.1				
Functional Failure: 1.1.2 - Slides off Track				
See FF no 1.3.3				
See FF 1.1.1				
Functional Failure: 1.1.3 - Slides on Track				
.01 - Wheel fails to rotate at required revs	.01.01 - Emergency breaking procedure	Tyre gets flat spot	uncomfortable train trip/coach is stopped	Train se t
	.01.02 - excess breaking force during normal braking			
	.01.03 - brake applied excessive force while no braking			
	.01.04 - wheel locks due to obstruction on track/foreign object			
.02 - Bearing seizes	.02.01 - Insufficient lubricant	Wheel locks & flat spots	coach is stopped	Train se t
	.02.02 - Broken seal			
	.02.03 - Bad recondition/manufacture			
	.02.04 - Damage during fitment			
	.02.05 - Damage due to bearing box			
Functional Failure: 1.1.4 - Rolls off Track				
.01 - Rolls off Track	Part of Infrastructure RCM analysis			
Functional Failure: 1.2.1 - No contact with break system when required				
Functional Failure: 1.2.2 - Not enough contact force to break system when required				
Functional Failure: 1.2.3 - To much contact force with break system when required				
Functional Failure: 1.2.4 - Contact with break system when not required				
Functional Failure: 1.3.1 - Wheel cracks				
.01 - Wheel cracks	.01.01 - Material flaw	loss of contact to track	derailment	(
	.01.02 - Severe Impact			
	.01.03 - Extreme temperature change			
.02 - Tyre cracks	.02.01 - Severe Impact	loss of contact to track	derailment	(
	.02.02 - Material Flaw			
	.02.03 - Weld breaks			
	.02.04 - Extreme Temperature change			
Functional Failure: 1.3.2 - Wheel loses roundness				
See FF no 1.3.3				
Functional Failure: 1.3.3 - Wheel wears to outside of tolerance				
.01 - profile outside of specification	.01.01 - Age/Wear out	Decreased performance	Uncomfortable ride	Ever (
	.01.02 - Locked wheel see FF - 1.1.3	Wheel locks & flat spots	coach is stopped	set ne
	.01.03 - Bad track condition	Decreased performance	Uncomfortable ride	Ever (
	.01.04 - Overloading			
Axle				
Functional Failure: 2.1.1 - Becomes detached from wheel				
.01 - Wheel internal diameter out of specification	.01.01 - Manufacturing error	lateral movement between wheel and axle, damages bearing box	coach derails	Train s
	.01.02 - Damage during recondition			
.02 - Axle exterior diameter out of specification	.02.01 - Damage during recondition			
	.02.02 - Manufacturing error			
Functional Failure: 2.2.1 - Inferior interference fit				
.01 - Axle is out of specification	See FF - 2.1.1.02	lateral movement between wheel and axle, damages bearing box	coach derails	Train s
.02 - Bearing internal diameter/surface out of specification	.02.01 - Incorrect manufacture			
	.02.02 - Incorrect reconditioning			
	.02.03 - Damage during press-fit			
Functional Failure: 2.2.2 - Bearings seize				
See FF 1.1.3.02				
.02 - Bearing Box damaged/out of specification	.02.01 - Damage during installation/removal	Causes damage to bearing and/or suspension mounts	loss of control, possible derailment	Train se se
	.02.02 - Damage due to impact			

Task Selection

		Selection guide							Candidate tasks	Effectiveness information	Sel. dec.
ponent/failure e	Failure cause	1	2	3	4	5	6	7			
on ring											
Becomes loose	.01.01 - Incorrect fitting	N	-	N	N	-	N	N	.01 - Post-assembly quality inspection	Low probability thus not cost effective	Introduce spot checks
	.01.02 - Damage during operation	N	-	N	N	-	Y	-	.01 - Visual Inspection	Good	.01 PdM
Ring cracks	.02.01 - Impact damage	N	-	N	N	-	Y	-	.01 - Visual Inspection	Good	.01 CD
- Wheel fails to e at required	.01.01 - Emergency breaking procedure	-	-	-	-	-	-	-	Forms part of breaking system, PAM tasks to be determined in brake system RCM		
	.01.02 - excess breaking force during normal braking	-	-	-	-	-	-	-			
	.01.03 - brake applied excessive force while no braking	-	-	-	-	-	-	-			
	.01.04 - wheel locks due to obstruction on track/foreign object	N	-	N	N	-	N	N	None	-	RTF
ing											
Bearing seizes	.02.01 - Insufficient lubricant	N	-	Y	Y	Y	-	-	.01 - Thermal camera scanning (fixed/mobile)	Unknown	No bearing inspection/test no information. Only intern
									.02 - Acoustic detection, (mounted/trackside)	Unknown	
									.03 - Heat sensitive bolts, remote reading	Unknown	
	.02.02 - broken seal	N	-	Y	Y	Y	-	-	Same as above (1.1.3.02.02.01)	Unknown	
	.02.03 - bad recondition/manufacture	N	-	Y	Y	N	N	N	.01 - Post manufacture/assembly spin test	Good	.01 PdM
	.02.04 - Damage during fitment	N	-	Y	Y	N	N	N	.01 - Post manufacture/assembly spin test	Good	.01 PdM
	.02.05 - Damage due to bearing box	N	-	N	Y	Y	N	N	.01 - visual/ultrasonic inspection	Good	.01 FF
el											
Wheel cracks	.01.02 - Severe Impact	N	-	N	N	-	N	N	None	-	RTF
	.01.03 - Extreme temperature change	N	-	Y	Y	Y	Y	-	.01 - Acoustic test, hammer or ultrasound	Average	.01 FF
									.02 - Same thermal system as Bearing (except the bolts)	Unknown	
Tyre cracks	.02.01 - Severe Impact	N	-	N	N	-	N	N	None	-	RTF
	.02.03 - Weld breaks	N	-	Y	Y	Y	N	N	.01 - Acoustic test, hammer or ultrasound	Low	RTF
	.02.04 - Extreme Temperature change	N	-	Y	Y	Y	Y	-	.01 - Acoustic test, hammer or ultrasound	Average	.01 FF
									.02 - Same thermal system as Bearing (except the bolts)	Unknown	-
profile outside of ification	.01.01 - Age/Wear out	Y	Y	Y	N	-	Y	-	.01 - Profile measurement	Good	.01 TDM
	.01.04 - Overloading	Y	Y	Y	N	-	N	N	.01 - Install load cells	Low	RTF
									.02 - Control Passenger numbers		
el											
- Wheel internal eter out of ification	.01.02 - Damage during recondition	N	-	Y	Y	N	N	N	.01 - Post manufacture/assembly spin test	Good	.01 PdM
- Axle exterior eter out of ification	.02.01 - Damage during recondition	N	-	Y	Y	N	N	N	.01 - Post manufacture/assembly spin test	Good	.01 PdM
ing Box											
- Bearing Box aged/out of ification	.02.01 - Damage during installation/removal	N	-	Y	Y	N	N	N	.01 Post fitment visual/acoustic test	Average	.01 PdM

Appendix G:

Under-Coach Wheel Set Machining Analysis Tables

Production Capacity - U2000-400 with one operator
Reprofiling - 1 mounted wheelset (2 wheels)

The production capacity of the Underfloor Wheel Lathe U2000-400 is consisting of the following individual times

Vehicle movement time
Positioning and clamping times
Measuring and machining times
Unclamping time

					min
1.0	***Vehicle movement time***				
1.1	Shunting of vehicle	depending on shunting system			5,00
1.2	Data input				1,00
2.0	***Positioning and clamping times***				
2.1	Positioning of wheelset				0,50
2.2	Clamping of wheelset	depending on axle box design			4,00
2.3	Ø-reflective foil to place				1,00
3.0	***Measuring and machining times***				
3.1	Pre measurement of wheelset				2,00
3.2	Machining of wheelset				
	Machining target		Reprofiling - one mounted wheelset		
	Wheel diameter worn	900 mm	both wheels simultaneously		
	Wheel diameter new	888 mm	with normal worn conditions		
	Tyre width	135 mm	Cutting speed range	35 - 84 m/min	
	Approx. length of cut	210 mm	Feed range up to	2,0 mm/rev	
	Depth of cut	6 mm	two cuts		
	Depth of cut (1)	4 mm	v = 45 m/min	s = 1,2 mm/rev	
	Depth of cut (2)	2 mm	v = 60 m/min	s = 1,0 mm/rev	
3.2.1	Machining time	first cut	Cross section of cut (1)	4,8 mm²	10,99
3.2.2	Intermediate Ø-measuring during cutting process				0,00
3.2.3	Machining time	second cut	Cross section of cut (2)	2,0 mm²	9,80
3.2.4	Machine (tool post) cleaning				1,00
3.3	Post measurement of wheelset				2,00
4.0	***Unclamping time***				
4.1	Unclamping of wheelset	depending on axle box design			2,00

Summary 3.0 "Measuring and Machining" Times **26**

Floor to floor time for one wheelset **39**

U2000-400 Capacity.xls 1 Reprofiling - Wheelset U2000-400

Table G1 Production capacity of the U2000-400 [51]

Production Capacity - MOBITURN with one operator
Reprofiling - 1 mounted wheelset (2 wheels) [2 cuts]

The production capacity of the MOBITURN Wheel Lathe
is consisting of the following individual times

Machine movement time
Positioning and clamping times
Measuring and machining times
Unclamping time

					min
1.0	***Machine movement time***				
1.1	Shunting of machine				3,00
1.2	Data input				1,00
2.0	***Positioning and clamping times***				
2.1	Positioning of machine				2,00
2.2	Clamping of wheelset	depending on axle box design			3,00
2.3	Ø-reflective foil to place				1,00
3.0	***Measuring and machining times***				
3.1	Pre measurement of wheelset				2,00
3.2	Machining of wheelset				
	Machining target		Reprofiling - one mounted wheelset		
	Wheel diameter worn	1000 mm	both wheels simultaneously		
	Wheel diameter new	990 mm	with normal wear conditions		
	Tyre width	135 mm	Cutting speed range	35 - 84 m/min	
	Approx. length of cut	210 mm	Feed range up to	2,0 mm/rev	
	Depth of cut	5 mm	two cuts		
	Depth of cut (1)	3 mm	v = 45 m/min	s = 1,2 mm/rev	
	Depth of cut (2)	2 mm	v = 60 m/min	s = 1,0 mm/rev	
3.2.1	Machining time	first cut	Cross section of cut (1)	3,6 mm²	12,21
3.2.2	Machine (tool post) cleaning				1,00
3.2.3	Intermediate Ø-measuring				1,00
3.2.4	Machining time	second cut	Cross section of cut (2)	2,0 mm²	10,92
3.2.5	Machine (tool post) cleaning				1,00
3.3	Post measurement of wheelset				2,00
4.0	***Unclamping time***				
4.1	Unclamping of wheelset	depending on axle box design			2,00
4.2	Machine cleaning				2,00

Summary 3.0 "Measuring and Machining" Times **30**

<u>Floor to floor time for one wheelset</u> ***44***

Table G2 Production capacity of the MOBITURN®2 [52]

Appendix H:

Selection of Information from the SARCC-Metrorail Main Agreement

ADDENDUM 2 [**10**]

ROLLING STOCK MAINTENANCE STANDARDS

	Standards reference	Description - area of relevance
1	5M2 Maintenance manuals	Description of preventative and corrective maintenance to be done on systems, sub-systems and subassemblies. Will be used during PS&C (Intermediate-), Full Sheds, fault finding and repairs. Will be used as baseline for upgrades & modifications. Supplied from original suppliers.
2	5M2 Repair manuals	Description of how repairs are done on subassemblies and components. Will also give specifications and testing procedures. Supplied from original equipment manufacturer/ suppliers.
3	Maintenance procedures	Original Equipment Manufacturer's developed maintenance standards. Used during Full- and Intermediate Shedding on specific components and subassemblies.
4	Carriage and Wagon manuals (Volume 1 & 2)	Complete instruction manual with procedures to maintain, inspect, test and measure plain trailer braking systems, bogies, wheels, draw gear and complete undercarriage. Used extensively by Carriage and Wagon maintenance personnel during shedding, fault finding, breakdowns, inspections and liftings.
5	High Voltage Safety instructions.	Safety Instructions governing the way maintenance personnel work with or on High voltage equipment. It provides the safe working procedures when working on High voltage equipment in the Rolling Stock maintenance environment.
6	Code of practice no. 2 Wheel and Axle manual	Use extensively during wheel inspections, measurements and repairs.
7	Code of practice no. 4 Rolling Stock Springs	Is applicable to determine the condition & maintenance standards of springs.
8	Code of practice no. 29 Safe Operation of machinery, plant and equipment.	This governs the way machinery and equipment are maintained and tested. The overhead cranes, lathes, compressors, Air system, Depot heaters, etc. have to apply to these standards.
9	Legislation.	• Act 85 of 1993, Occupational Health and Safety. • Act 66 of 1995, Labour Relations Act. • Act 75 of 1997, Basic Conditions of Employment.
10	6M, 7M, 8M Manuals	Same as item 1 & 2 above

ADDENDUM 3 [10]

ROLLING STOCK MAINTENANCE PROGRAM

INDEX

Maintenance program:

1. Preventive Maintenance

1.1 Passenger safety & comfort (PS&C or Intermediate Shed)

In service inspection ***(2 weekly cycle for the Cape Region, Pretoria Region, Wits Region and Durban Region)*** which entails measurement, cleaning, change out, repair and testing of all safety critical aspects such as wheels, doors, hooters, brakes, lights and control instrument gauges. Check passengers comfort requirements e.g. heating. Check oil levels and brush wear on all rotating machines. Do non-critical in-service repairs. The required work is done by suitably qualified personnel on an inspection pit in the allocated maintenance sheds. Sequence-, power- and brake tests are done after completion of work where after the Rolling Stock is certified as ready for service.
In service Inspection & Repair of all passenger and driver safety & comfort related equipment must be done by suitably qualified personnel.

	System name or Work done	Description of repairs done on system, component or sub-assembly	Maintenance standards
1.1.1	High Tension Traction System	-Check & Repair worn components on pantograph, test for correct functioning. -Examine Traction Motor commutator, suspension bearing and brush gear. Clean where necessary and lubricate. -Inspect and repair all High Tension (HT) & low Tension (LT) -equipment. -Examine all High Tension (HT) cables and Low Tension (LT) Wiring. -Inspect gear cases for leaks and lubricate.	-Refer to shedding checklists. -Maintenance- and repair manuals.
1.1.2	Electric Control System	-Check and repair worn components or defective components. -Check and change-out all defective Auto Notching Equipment. -Inspect, clean or repair all defective electrical components.	-As Above

1.1.3	Body	-Examine vacuum pipes for leaks. -Do vacuum tests after all repairs are done -Examine all air pipes. -Examine inner and outer stem guides on vestibule couplers. -Inspect & Repair all doors for free movement. Check correct speed. Perform electrical test for correct functioning. -Examine & repair defective lights. -Inspect and repair heating system -Examine & repair Hooters and Wipers	-As Above -C&W Handbook Volume 2
1.1.4	Body (Vehicle Building)	-Examine all windows, seats, wall-panels, the ceiling, partitions and end doors. -Examine & Repair all damaged & vandalised interior- and exterior equipment applicable to Vehicle Building. -Remove graffiti	-Maintenance and component overhaul manuals.
1.1.5	Auxiliary Equipment	-Inspect and repair all defective and worn components on auxiliary equipment. -Examine and check commutator, bearing and brush wear. -Lubrication and inspect Compressor and Exhauster	Refer to 1.1.1.
1.1.6	Coach Compressed Air System	-Examine & repair air system for leaks or damage. Change defective components	-As Above
1.1.7	Coach Steering and Support	-Examine bogies and wheels for cracks and any wear & tear. -Examine coil springs and snubbers for cracks and wear & tear. -Examine wheels for the following defects: High, sharp, or thin flanges, skidded wheels, grooved and loose tyres. -Examine bogies and repair where necessary. -Visually examine axle boxes.	-As Above -C&W Handbook Volume 2 -Code of Practice no 2 -C&W checklist
1.1.8	Brake system	-Examine all Brake Blocks, measure and renew or replace where necessary. -Examine all Brake Gear components and repair where necessary. -Renew defective slack adjusters. -Vacuum test brake system.	-C&W Handbook Volume 2

1.2 Full Shedding

The Regional schedules are as follows:

Wits: 18,000km in-service preventative maintenance program carried out on a 4,6,8 or 12 week cycle.

Capetown: 18,000km in-service preventative maintenance program carried out on an 8week cycle.

Pretoria: 18,000km in-service preventative maintenance program.

Durban: 18,000km in-service preventative maintenance program.

The program entails the Inspection, condition monitoring, lubricating, cleaning and/or replacing of all High Tension (HT) and low Tension (LT) electrical- and mechanical-, roof equipment, body and undercarriage. Suitably qualified personnel must do the required work in the inspection pits in the allocated maintenance sheds. Program work and smaller modifications are done.

Sequence-, power- and brake tests are done after completion of work and the train set is then certified as road worthy and ready for service.

All Passenger safety & Comfort maintenance is also done.

	System name or Work done	Description of repairs done on system, component or sub-assembly
1.2.1	High Tension (HT) Traction system	-Check & Repair worn and defective components on Pantograph. Test for correct functioning, grease and lubricate. -Examine Traction Motors Commutators, Suspension Bearings and brush wear. Clean, repair, lubricate & replace where necessary. -Inspect & Repair all defective High Tension (HT) & LT Equipment. Clean and lubricate. Test for correct functioning of Switch Gear. -Clean & Vacuum High Tension (HT) Compartment. -Examine & Repair all High Tension (HT) Cables and LT Wiring -Inspect Gears & Gear cases for leaks and lubricate
1.2.2	Electric Control System	-Inspect, Clean & Repair defective mechanical- and electrical components. -Test & change detective or worn components on Master Controller
1.2.3	Body	-Examine coupler for wear & tear. -Examine inner- and outer stem guides and Vestibule couplers. -Inspect & repair all doors for free movement and correct speed. Electrically test for correct operation. -Examine & repair defective lights and clean lights fittings. -Inspect and repair heating system -Inspect & repair hooter and wipers

1.2.4	Body (Vehicle Building)	-Examine & repair Windows, Floors, Seats, Wall Panels, Ceiling, Partitions, Doors, Roof ventilation and Catwalks, Step Boards & Trimming. -Examine & Repair all interior and exterior equipment for damage and vandalism -Repair Toilets -Remove graffiti
1.2.5	Auxiliary Equipment	-Inspect, clean and change of defective and worn components. -Examine & check Commutator condition, Bearing and Brush wear. -Condition monitoring on Compressor & Exhauster
1.2.6	Coach Compressed Air Supply System	-Examine air system for damage or leaks. Repair where defective. -Change out Valves on Program Work schedules.
1.2.7	Steering and coach body support	-Examine Bogie for cracks, wear and missing split pins and replace where necessary. -Examine Coil springs and Snubbers for cracks, wear, brakeages and perished rubbers. -Examine and measure Wheel wear and profile of all Wheels.
1.2.8	Program work	-Program Work done on components as per applicable schedule.
1.2.9	Brake system	-Examine carefully all brake blocks. Replace brake blocks where needed. -Examine carefully all the brake gear. Replace or repair where needed. -Replace defective slack-adjusters. -Vacuum-test the braking system.

1.3 Carriage and Wagon Lifting

Scheduled 18month preventative maintenance of undercarriage, frame, body and brake system on Plain Trailers, ***and on Motor Coaches as-and-when they undergo Corrective Maintenance***. Coaches are withdrawn from service for the inspection, measurement, replacement or renewal of all defective or worn components or parts. Before being placed back into service, all systems and components are tested and the coach is then declared roadworthy. Work performed by suitably qualified personnel.

	System name or Work done	Description of repairs done on system, component or sub-assembly
1.3.1	Body. (Draw gear)	-Examine and repair all Draw gears. Measure bushes and replace or renew where necessary. -Inner and Outer Stem Guides, Vestibule Couplers and Stem Guide Rods are examined and repaired where necessary.
1.3.2	Brake system	-All Vacuum Cylinders are overhauled every 36 months on Motor coaches & Plain trailers. They are stripped, cleaned, examined, assemble and tested. -Slack Adjusters are tested, overhauled and/or replaced -Brake Gear components are examined for wear and tear and replaced or renewed. -Brake Blocks must be measured against the required standards and renewed or replaced where necessary. -All Vacuum pipes are examined and repaired, cleaned or replaced. -Brake system is adjusted and tested
1.3.3	Coach steering and support (Wheel and Bogie)	-Examine wheels for visible defects. -Link, Brake-, split pins are examined, measured and replaced where necessary.

Appendix I:

Scheduled Maintenance Check Lists

Pages XLIV to XLVIII cover the check sheet for the PS&C, as supplied by the Planning Department of Rolling Stock and re-printed with their permission. [**36**]

A SHED – (PS&C) 5M2/5M2A ELECTRICAL FITTER CHECK SHEET					prasa
File Ref	DOCS_MHQ-#71498-V5-A_SHED_-_ELECTRICAL_FITTER_CHECK_SHEET				
Creation Date	2010-01-19		Last Edit Date	2010-10-20	
Doc No. & Version	71498 V5	Author	Tino Gabryk	Page 1 of 5	
Volume and Addition	Vol. 1, 1st Addition	Approved	Dr. D. Mthimkhulu		

SET NO.	COACH NO.	RESPONSIBLE PERSONS	RES.	TIME START	TIME COMPLETE	DATE
			EF.			
			EF			
			TH. OIL			

GENERAL RESPONSIBILITIES

Before commencing with a shed examination, the electrical fitters and trade hand must comply with the High Voltage Safety Instructions.
Check the job request for any defects booked.
It is the responsibility of the electrical fitter to ensure that all covers, panels and screens are replaced and properly secured before the train set is tested. This is especially important where high voltage equipment is concerned.
It is important that every member of the personnel commence work promptly and sign off the work permit immediately on completion of his/her work so that the train set can be tested and released on time.
Furnish all detailed work done, this includes time taken to R&R components.
Write in detail, neat and in printed hand writing.
All relevant personnel to sign where required.
Failure to comply will be delt with in accordance to corporate governance.

DUTIES

The electrical fitter must test all the Q.S.A.S electrically when the train set come on the pit before the overhead supply is isolated and notify the responsible trade hand of any defective valves.
Lower the pantographs.
Place personnel lock on the applicable pit road isolating switch ensuring the pit road to be worked on is isolated and earthed.
Sign the work permit.
The trade hand (oiling) must report abnormal oil consumption to the supervisor who must investigate it.
Trade hand (oiling) must record the quantity of lubricants used per coach and sign the checklist
The trade hand (electrical fitter) must assist the elect. fitter to perform his duties, remove and replace covers and arc chutes.
The Technical Supervisor must conduct ad-hoc Quality Compliance Audits during shedding
Correct tools must be used for any duty performed.

SHEDDING

The air testing and adjustments of the pantograph is to be completed before the opening of the auxiliary compartment.
After opening of the high-tension compartment the electrical fitter must ensure that the isolating and earthing switches are in the earth position and that at least 80 % of the knife switch blade surfaces make proper contact.
All equipment must be examined, tested and repaired or reported to the supervisor if unable to repair
Motor coaches must be sequence tested after examination and repair.
The complete train set must be tested as per test procedure on completion of work.
The following check list must be completed for each coach.

NOTE: **The entire checklist must be completed for an A shed**
All maintenance work standards needs to conform to 5M2A maintenance manuals.

ACTIVITY	ACCEPTANCE CRITERIA	OK / NOT OK	REMARKS AND REPAIRS TO BE DONE	REPAIRED	TIME TO REPAIR
		X / √		X / √	MIN.

A SHED – (PS&C) 5M2/5M2A ELECTRICAL FITTER CHECK SHEET				
File Ref	DOCS_MHQ-#71498-V5-A_SHED_-_ELECTRICAL_FITTER_CHECK_SHEET			
Creation Date	2010-01-19		Last Edit Date	2010-10-20
Doc No. & Version	71498 V5	Author	Tino Gabryk	Page 2 of 5
Volume and Addition	Vol. 1, 1st Addition	Approved	Dr. D. Mthimkhulu	

prasa

ACTIVITY		ACCEPTANCE CRITERIA	OK / NOT OK X / √	REMARKS AND REPAIRS TO BE DONE	REPAIRED X / √	TIME TO REPAIR MIN.
1	**Cab:**					
1.1.	Test QSA	Max 7 seconds				
1.2.	Drivers Brake Valve- contact fingers, wiring, free movement under vacuum conditions, handle and spider	Visual Examination				
1.3.	Master Controller - free movement	Operational Test				
1.4.	Meters - Calibration Date, Bent Needles, Glass	Visual Examination				
1.5.	Siren and foot pedal	Operational Test				
1.6.	Pantograph operating valve – test mechanically and electrically	Operational Test				
1.7.	Head light dimmer switch – test	Operational Test				
1.8.	Cab heaters (x2) - test both	Operational Test				
1.9.	Bell and bell push switches - test	Operational Test				
1.10.	Wiper control and motor - test and examine and drain water, blow system clean, clean water trap, check wiper blades	Clean then Operational Test				
1.11.	Train number indicator - test and examine numbers, operation of light, cover, locks and knee brace	Visual Examination and Operational Test				
1.12.	MG/MA, pressure fan, blower fan and line switch indicator lights – test	Operational Test				
1.13	Sunvisor - test and examine	Visual Examination				
1.14.	Compressor and exhauster overload panels - test and examine, clean contacts	Trip Test				
1.15	Lighting relay - test and examine	Operational Test				
1.16	MA / MG. overload, Low Tension contactors - compressor, exhauster,	Operational Test Contact Gap. 10 mm Min (LT Contactor) Check cal. seal if broken Recalibrate/Replace				
1.17	MA /MG contactors - examine	Visual Examination				
1.18	Voltage regulator – service, renew brushes, adjust, test and clean	Carbon Gap. 1 2 mm				
1.19	Control, heater, door positive, compressor and exhauster circuit breaker - test and examine (Trip Test)	Operational Test				
1.20.	Fire extinguisher (only on Leading Heads) - check if sealed, check date - securing bracket	Visual Examination				
1.21.	Low tension door lock - door closing properly	Operational Test				
2	**High Voltage Compartment: 5M2A, 5M2B**					
2.1	Blower fan circuit breakers - test and examine	Operational Test and Visual Examination				
2.2	Line, combination, resistance switches and reverser - test EP valves, examine switches and interlock fingers/contacts (sequence test)	No Leaks, Interlock Fingers Clean Interlock Fingers Must Make Contact				
2.3	Traction motor overloads – examine and set flags (Trip Manually and Reset	Operational Test and Visual Examination				

A SHED – (PS&C) 5M2/5M2A ELECTRICAL FITTER CHECK SHEET					
File Ref	DOCS_MHQ-#71498-V5-A_SHED_-_ELECTRICAL_FITTER_CHECK_SHEET				
Creation Date	2010-01-19		Last Edit Date	2010-10-20	
Doc No. & Version	71498 V5	Author	Tino Gabryk	Page 3 of 5	
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	ACTIVITY	ACCEPTANCE CRITERIA	OK / NOT OK X / √	REMARKS AND REPAIRS TO BE DONE	REPAIRED X / √	TIME TO REPAIR MIN.
	Electrically) Operational Test					
3	**High Voltage Compartment: 5M2A, 5M2B**					
3.1.	Traction motor cut out switches – examine	Operational Test				
3.2. 3.3	Current limit relay, TDR, static notching relay .Operational Test & Visual examination.	Check Cal. seal if broken. Recalibrate/Replace				
3.4.	DCCT – examine	Visual Examination				
3.5.	Holding relay – examine	Operational Test				
3.6.	All high and low tension cables and wiring - examine	Visual Examination				
4	**Auxiliary High Voltage Compartment:**					
4.1.	Pantograph air cock and globe valve – service and test	Operational Test				
5	**Roof:**					
5.1.	Pantograph - examine wearing strip thickness, worn knuckles and links, shunt and knuckle straps, rusted tubes, balancing gear, air leaks, raise and lower time, weight, insulators not damaged	Operational Test following. Strip Thickness: Min 2 mm Inspect links for wear & tear Raise Time: 10 - 20 Sec. Lowering Time: < 6 Sec Weight: 7.4 - 8.2 kg (Preferred 7.9 kg) Side Play (Old Type): Max 25 mm and Tighten panto horn nuts Visual Examination				
5.2.	Roof steps – examine for rust, properly secured	Visual examination				
6	**Under-frame:**					
6.1.	Jumper cables and receptacles - damaged insulation, secure, electrical connections damage or burnt. Covers fitted and not damaged. Cables plugged in properly and secured	Visual Examination Test Cross 2 core				
6.2	E.V.V. and Q.S.A. valves - secure	No Pull Through QSA must work Mechanically and Electrically QSA Leak off Time Max 6 Sec				
6.3	Accelerating resistors – insulators, ribbons, connections, cables, splash tray	Visual Examination and remove and replace all temporary connections				
6.4.	Door and HT. reducing valve - air leaks	Visual Examination				
6.5	Main and door reservoirs - damage, air leaks	Visual Examination				
6.6.	Wiper drain valve - air leaks. Blocked	Visual Examination				
6.7	Spirex valve to service	Operational Test				
6.8	Duplex check valve - air leaks, secure (490 - 520kpa)	Visual Examination & Test				
6.9	Traction motor connection boxes – covers secure	Visual Examination				
6.10	Draw Gear	Visual Examination				
6.11.	Earth cable check, body to bogie and bogie to axle	Visual Examination				

A SHED – (PS&C) 5M2/5M2A ELECTRICAL FITTER CHECK SHEET				
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ACTIVITY	ACCEPTANCE CRITERIA	OK / NOT OK X / √	REMARKS AND REPAIRS TO BE DONE	REPAIRED X / √	TIME TO REPAIR MIN.
7 **Bogie:**					
7.1. Visual examination of entire bogie 1 and bogie 2 for any defects	Visual Examination				
7.2. Speedo generator and probes - cables, probes and generators secured	Visual Examination				
7.3 Resilient bush wear (During Power Testing)	Observe and Report				
8 **Trade Hand - Oiling And Filters:**					
8 1 Panto skate graphite grease	2 kg				
8.2 Exhauster oil	Fill to max. Level (report excessive use) Record quantity used.				
8.3 Gear cases	Fill to max level				
8.4 Compressor oil	Fill to max level (report excessive use) Record quantity used				

MATERIAL USED — **Mark applicable item with an X**

COACH NO.	SERIAL NO.	DESCRIPTION	QUANTITY

COACH NO.	EFFECTIVE REPAIRS NOT DONE PLEASE LIST AND REASON WHY

A SHED – (PS&C) 5M2/5M2A ELECTRICAL FITTER CHECK SHEET				
File Ref	DOCS_MHQ-#71498-V5-A_SHED_-_ELECTRICAL_FITTER_CHECK_SHEET			
Creation Date	2010-01-19		Last Edit Date	2010-10-20
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ACTIVITY	ACCEPTANCE CRITERIA	OK / NOT OK	REMARKS AND REPAIRS TO BE DONE	REPAIRED	TIME TO REPAIR
		X / √		X / √	MIN.

COACH NO.	ADDITIONAL INSTRUCTIONS (MONITORING)

Important notice: It is the responsibility of the artisan shedding a motor coach to ensure that all work is done according to the required specifications and Quality standards reflected in the 5M2A Maintenance manuals.
The Technical Supervisor in charge is responsible and accountable for all work done on any coach shedded by his/her team and therefore must satisfy him / her that all work is done according to the required specifications and Quality Standard by conducting regular task observations.
<u>It is the responsibility of the Quality Assurance representative and maintenance service team to ensure the technical cleaning is effective and executed on the maintenance specific areas identified.</u>

Always observe safety rules and regulations.

Grade	Surname & Initials	Signature	Date
Tech. Supervisor			
Electrical Fitter			
Trade Hand			

CHANGE LIST

REVISION NUMBER	DESCRIPTION OF CHANGE	PAGE	DATE OF CHANGE
1.	Changed header and footer to Metrorail standard	1	19/01/2010
2.	Removed all rotary machine brush examination interventions	All	09/04/2010
3.	Replace Metrorail logo with PRASA logo	All	21/06/2010
4.	Reviewed supervisor responsibility by including task observations	4	21/06/2010
5.	Added file reference and Dr. D. Mthimkhulu	all	20/10/2010

Pages XLIX to LV cover the check sheet for the Intermediate Shed, as supplied by the Planning Department of Rolling Stock and re-printed with their permission. [**36**]

B SHED – (INTER) 5M2/5M2A/10M ELECTRICAL FITTER CHECK SHEET				
File Ref	DOCS_MHQ-#87635-V1-B_SHED_-_ELECTRICAL_FITTER_CHECK_SHEET			
Creation Date	2010-01-19		Last Edit Date	2011-02-20
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SET NO.	COACH NO.	RESPONSIBLE PERSONS	RES.	TIME START	TIME COMPLETE	DATE
			EF.			
			EF			
			TH. OIL			

GENERAL RESPONSIBILITIES

Before commencing with a shed examination, the electrical fitters and trade hand must comply with the High Voltage Safety Instructions.

Check the job request for any defects booked.

It is the responsibility of the electrical fitter to ensure that all covers, panels and screens are replaced and properly secured before the train set is tested. This is especially important where high voltage equipment is concerned.

It is important that every member of the personnel commence work promptly and sign off the work permit immediately on completion of his/her work so that the train set can be tested and released on time.

Furnish all detailed work done, this includes time taken to R&R components.

Write in detail, neat and in printed hand writing.

All relevant personnel to sign where required.

Failure to comply will be delt with in accordance to corporate governance.

DUTIES

The electrical fitter must test all the Q.S.A.S electrically when the train set come on the pit before the overhead supply is isolated and notify the responsible trade hand of any defective valves.

Lower the pantographs.

Place personnel lock on the applicable pit road isolating switch ensuring the pit road to be worked on is isolated and earthed.

Sign the work permit.

The trade hand (oiling) must report abnormal oil consumption to the supervisor who must investigate it.

Trade hand (oiling) must record the quantity of lubricants used per coach and sign the checklist

The trade hand (electrical fitter) must assist the elect. fitter to perform his duties, remove and replace covers and arc chutes.

The Technical Supervisor must conduct ad-hoc Quality Compliance Audits during shedding

Correct tools must be used for any duty performed.

SHEDDING

The air testing and adjustments of the pantograph is to be completed before the opening of the auxiliary compartment.

After opening of the high-tension compartment the electrical fitter must ensure that the isolating and earthing switches are in the earth position and that at least 80 % of the knife switch blade surfaces make proper contact.

All equipment must be examined, tested and repaired or reported to the supervisor if unable to repair

Motor coaches must be sequence tested after examination and repair.

The complete train set must be tested as per test procedure on completion of work.

The following check list must be completed for each coach.

NOTE: The entire checklist must be completed for an A shed
All maintenance work standards needs to conform to 5M2A maintenance manuals.

ACTIVITY	ACCEPTANCE CRITERIA	OK / NOT OK	REMARKS AND REPAIRS TO BE DONE	REPAIRED	TIME TO REPAIR
		X / √		X / √	MIN.

B SHED – (INTER) 5M2/5M2A/10M ELECTRICAL FITTER CHECK SHEET				
File Ref	DOCS_MHQ-#87635-V1-B_SHED_-_ELECTRICAL_FITTER_CHECK_SHEET			
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ACTIVITY	ACCEPTANCE CRITERIA	OK / NOT OK X / √	REMARKS AND REPAIRS TO BE DONE	REPAIRED X / √	TIME TO REPAIR MIN.
1 **Cab:**					
1.1. Test QSA	Max 7 seconds				
1.2. Drivers Brake Valve- contact fingers, wiring, free movement under vacuum conditions, handle and spider	Visual Examination				
1.3. Master Controller - free movement	Operational Test				
1.4. Meters - Calibration Date, Bent Needles, Glass	Visual Examination				
1.5. Siren and foot pedal.	Operational Test				
1.6. Pantograph operating valve – test mechanically and electrically	Operational Test				
1.7. Head light dimmer switch – test	Operational Test				
1.8. Cab heaters (x2) - test both	Operational Test				
1.9 Bell and bell push switches – test	Operational Test				
1.10. Wiper control and motor - test and examine and drain water, blow system clean, clean water trap, check wiper blades	Clean then Operational Test				
1.11 Train number indicator - test and examine numbers, operation of light, cover, locks and knee brace	Visual Examination and Operational Test				
1.12. MG/MA, pressure fan, blower fan and line switch indicator lights - test	Operational Test				
1.13. Sunvisor - test and examine	Visual Examination				
1.14. Compressor and exhauster overload panels - test and examine clean contacts.	Trip Test				
1.15. Lighting relay - test and examine	Operational Test				
1.16 MA. / MG. overload, Low Tension contactors - compressor, exhauster.	Operational Test Contact Gap: 10 mm Min (LT Contactor) Check cal. seal if broken Recalibrate/Replace				
1.17 MA /MG contactors - examine	Visual Examination				
1.18 Voltage regulator – service, renew brushes, adjust, test and clean	Carbon Gap: 1.2 mm				
1.19. Control, heater, door positive, compressor and exhauster circuit breaker - test and examine (Trip Test)	Operational Test				
1.20. .Fire extinguisher (only on Leading Heads) - check if sealed, check date - securing bracket	Visual Examination				
1.21 Low tension door lock – door closing properly	Operational Test				
2 **High Voltage Compartment: 5M2A, 5M2B**					
2.1. Blower fan circuit breakers – test and examine	Operational Test and Visual Examination				
2.2. Line, combination, resistance switches and reverser - test EP valves, examine switches and interlock fingers/contacts (sequence test)	No Leaks, Interlock Fingers Clean Interlock Fingers Must Make Contact				
2.3 Traction motor overloads – examine and set flags (Trip Manually and Reset	Operational Test and Visual Examination				

B SHED – (INTER) 5M2/5M2A/10M ELECTRICAL FITTER CHECK SHEET					prasa
File Ref	DOCS_MHQ-#87635-V1-B_SHED_-_ELECTRICAL_FITTER_CHECK_SHEET				
Creation Date	2010-01-19		Last Edit Date	2011-02-20	
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	ACTIVITY	ACCEPTANCE CRITERIA	OK / NOT OK X / √	REMARKS AND REPAIRS TO BE DONE	REPAIRED X / √	TIME TO REPAIR MIN.
	Electrically) Operational Test					
3	**High Voltage Compartment: 5M2A, 5M2B**					
3.1	Traction motor cut out switches – examine	Operational Test				
3.2. 3.3.	Current limit relay, TDR, static notching relay .Operational Test & Visual examination.	Check Cal. seal if broken Recalibrate/Replace				
3.4.	DCCT – examine	Visual Examination				
3.5.	Holding relay – examine	Operational Test				
3.6.	All high and low tension cables and wiring - examine	Visual Examination				
4	**Auxiliary High Voltage Compartment:**					
4.1.	Pantograph air cock and globe valve – service and test	Operational Test				
5	**Roof:**					
5.1.	Pantograph - examine wearing strip thickness, worn knuckles and links, shunt and knuckle straps, rusted tubes, balancing gear, air leaks, raise and lower time, weight, insulators not damaged	Operational Test following: Strip Thickness: Min 2 mm Inspect links for wear & tear Raise Time: 10 - 20 Sec. Lowering Time: < 6 Sec Weight 7.4 - 8.2 kg (Preferred 7.9 kg) Side Play (Old Type): Max 25 mm and Tighten panto horn nuts Visual Examination				
5.2.	Roof steps – examine for rust, properly secured	Visual examination				
6	**Under-frame:**					
6.1.	Jumper cables and receptacles – damaged insulation, secure, electrical connections damage or burnt. Covers fitted and not damaged. Cables plugged in properly and secured	Visual Examination Test Cross 2 core				
6.2.	E.V.V. and Q.S.A. valves – secure	No Pull Through QSA must work Mechanically and Electrically QSA Leak off Time: Max 6 Sec.				
6.3.	Accelerating resistors – insulators, ribbons, connections, cables, splash tray	Visual Examination and remove and replace all temporary connections				
6.4.	Door and HT. reducing valve - air leaks	Visual Examination				
6.5.	Main and door reservoirs - damage, air leaks	Visual Examination				
6.6.	Wiper drain valve - air leaks. Blocked	Visual Examination				
6.7.	Spirex valve to service	Operational Test				
6.8.	Duplex check valve - air leaks, secure (490 - 520kpa)	Visual Examination & Test				
6.9.	Traction motor connection boxes covers secure	Visual Examination				
6.10.	Draw Gear	Visual Examination				
6.11.	Earth cable check, body to bogie and bogie to axle	Visual Examination				

B SHED – (INTER) 5M2/5M2A/10M ELECTRICAL FITTER CHECK SHEET					
File Ref	DOCS_MHQ-#87635-V1-B_SHED_-_ELECTRICAL_FITTER_CHECK_SHEET				
Creation Date	2010-01-19		Last Edit Date	2011-02-20	
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ACTIVITY	ACCEPTANCE CRITERIA			OK / NOT OK X / √	REMARKS AND REPAIRS TO BE DONE	REPAIRED X / √	TIME TO REPAIR MIN.
6.12. Exhauster - oil leaks, foundation bolts and mountings, oil tank, sight glass, coupling, silencer, pipes, check valve, brushes, commutator, brush box, insulators, filter, oil feeder pipe strainer	Visual Examination and clean Operational Test Brush Reading ……………(brush box "A")						
6.13. Exhauster Functional Test minimum Watson disk reading 45kpa	Measure Reading ………….						
6.14. Exhauster hour meter reading	Yes No						
6.15 Compressor - oil leaks, foundation bolts, brushes, commutator, insulators, brush box, flex pipe, non return valve, cooling pipes.	Visual Examination Operational Test Brush Reading ……….. ..						
6.16. Compressor hour counter available	Yes No						
6.17. Motor alternator / generator - H.T. brushes, L.T. brushes, slip ring, commutator, covers, centrifugal switch, brush box, connections, earth cables, mounting bolts and brackets, choke, fan covers, decals and signage. Clean connection bus bar on connection box	Measure, inspect and secure all brushes. Slip ring, Comm inspect & check for defects. Covers to secure with the key Inspect for any insulation breakdown or damage Brush Reading ………..						
6.18. Exhauster, Compressor, MA/MG Commutator Condition	1 – Oily Dirt 2 - Dry Dirt 3 – Dull 4 – Light Brown 5 – Chocolate Brown	EXH COMPR MA/MG					
6.19					Comp		
6.20					MA / MG		
6.21							
7 **Bogie:**							
7.1. Traction motor examine - brushes, brush box, commutator, v-rings, brush box arms, interconnections, gear case, arc horn, keep bolts, rotating indicator, nose suspension, earth return brush, external cables and covers fittedInspect effect of spark caused by incorrect & non-uniform brush spring pressure, effect of high mica & rough comm Inspect & measure brush appearance from excessive clearance holder. Clean v-rings, check comm. Discoloring	Move brush up and down (prev clogging).Ensure correct brush angle 30° to 37°.Ensure no pitting of brush face Ensure good comm. surface WASHED AND CLEANED?? Brush Reading						
7.2 Traction Motors Commutator Condition	1 – Oily Dirt 2 - Dry Dirt 3 – Dull 4 – Light Brown 5 – Chocolate Brown	TM1 TM2 TM3 TM4					

B SHED – (INTER) 5M2/5M2A/10M ELECTRICAL FITTER CHECK SHEET				
File Ref	DOCS_MHQ-#87635-V1-B_SHED_-_ELECTRICAL_FITTER_CHECK_SHEET			
Creation Date	2010-01-19		Last Edit Date	2011-02-20
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ACTIVITY	ACCEPTANCE CRITERIA	OK / NOT OK	REMARKS AND REPAIRS TO BE DONE	REPAIRED	TIME TO REPAIR
		X / √		X / √	MIN.
7.3. Visual examination of entire bogie 1 and bogie 2 for any defects.	Visual Examination				
7.4. Speedo generator and probes – cables, probes and generators secured	Visual Examination				
7.5. Resilient bush wear (During Power Testing)	Observe and Report				
8 Trade Hand - Oiling And Filters:					
8.1 Pantograph skate graphite grease	2 kg				
8.2 Exhauster oil	Fill to max. Level (report excessive use) Record quantity used.				
8.3 Gear cases	Fill to max level				
8.4 Compressor oil	Fill to max level (report excessive use) Record quantity used				

MATERIAL USED — **Mark applicable item with an X**

COACH NO.	SERIAL NO.	DESCRIPTION									QUANTITY
		Traction motor no. 1 Brush box	A		B		C		D		
		Traction motor no. 2 Brush box	A		B		C		D		
		Traction motor no. 3 Brush box	A		B		C		D		
		Traction motor no. 4 Brush box	A		B		C		D		
		MA/MG	HT Brush				LT Brush				
		Exhauster									
		Compressor									
		Traction Motor Blowers	Blower fan no. 1+2				Blower fan no. 3+4				
		Pressure fan									
		Voltage regulator carbon brushes									

COACH NO.	EFFECTIVE REPAIRS NOT DONE PLEASE LIST AND REASON WHY

ACTIVITY	ACCEPTANCE CRITERIA	OK / NOT OK	REMARKS AND REPAIRS TO BE DONE	REPAIRED	TIME TO REPAIR
		X / √		X / √	MIN.

COACH NO.	ADDITIONAL INSTRUCTIONS (MONITORING)

Important notice: It is the responsibility of the artisan shedding a motor coach to ensure that all work is done according to the required specifications and Quality standards reflected in the 5M2A Maintenance manuals.
The Technical Supervisor in charge is responsible and accountable for all work done on any coach shedded by his/her team and therefore must satisfy him / her that all work is done according to the required specifications and Quality Standard by conducting regular task observations.
<u>It is the responsibility of the Quality Assurance representative and maintenance service team to ensure the technical cleaning is effective and executed on the maintenance specific areas identified.</u>

Always observe safety rules and regulations.

Grade	Surname & Initials	Signature	Date
Tech. Supervisor			
Electrical Fitter			
Trade Hand			

CHANGE LIST

REVISION NUMBER	DESCRIPTION OF CHANGE	PAGE	DATE OF CHANGE

B SHED – (INTER) 5M2/5M2A/10M ELECTRICAL FITTER CHECK SHEET				
File Ref	DOCS_MHQ-#87635-V1-B_SHED_-_ELECTRICAL_FITTER_CHECK_SHEET			
Creation Date	2010-01-19		Last Edit Date	2011-02-20
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Pages LVI to LXVI cover the check sheet for the Full Shed, as supplied by the Planning Department of Rolling Stock and re-printed with their permission. [**36**]

C SHED (FULL SHED) – CONSOLIDATED ELECTRICAL FITTER CHECK				
File Ref				
Creation Date	05/09/2011		Last Edit Date	05/09/2011
Doc No. & Version	#71514v3	Author	Tino Gabryk	Page 1 of 11
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SET NO.	COACH NO.	RESPONSIBLE PERSONS	RES.	TIME START	TIME COMPLETE	DATE
			EF			
			EF			
			TH. OIL			

ODO. Reading		CPU. Serial No.	

Micro to download prior to examination	X / √	

GENERAL RESPONSIBILITIES

Before commencing with a shed examination, the electrical fitters must check all job requests for any defects booked.
It is the responsibility of the electrical fitter to ensure that all covers, panels and screens are replaced and properly secured before the trainset is tested. This is especially important where high voltage equipment is concerned.
It is important that every member of the personnel commences work promptly and signs off the work permit immediately on completion of his/her work so that the train set can be tested and released on time.
Furnish all detailed work done, this includes time taken to R&R components.
Write in detail, neat and in printed hand writing. All relevant personnel to sign where required.

DUTIES

The electrical fitter must test all the QSA's electrically when the train set comes on to the pit before the overhead supply is isolated and notify the responsible trade hand of any defective valves. QSA's to be tested for pulling through.
Lower the pantographs.
Place personnel lock on the applicable pit road isolating switch ensuring the pit road to be worked on is isolated and earthed.
Sign the work permit.
The trade hand (oiling) must report abnormal oil consumption to the supervisor who must investigate it.
Trade hand (oiling) must record the quantity of lubricants used per coach and sign the checklist
The trade hand (electrical fitter) must assist the Elect. Fitter to perform his duties, remove and replace covers and arc chutes.
The Technical Supervisor must conduct ad-hoc Quality Compliance Audits during shedding, ensure that he/she is present at final train set tests and conducts ad hock walk about on pit area before tea and lunch breaks.

SHEDDING

After opening of the high-tension compartment the electrical fitter must ensure that the isolating switches are in the earth position and that at least 80 % of the knife switch blade surfaces make proper contact.
The air testing and adjustments of the pantograph is to be completed after the opening of the auxiliary compartment.
All equipment must be examined, tested and repaired or reported to the supervisor if unable to repair and missing equipments must be recorded on the job card / checklist.
Motor coaches must be sequence tested after examination and repair.
The complete train set must be tested as per test procedure on completion of work.
During Power test check resilient bush wear.
Remove and replace all program work components as per OEM schedule and date mark component indicating month and year.
Were their any mission critical components cut out? If yes state components and reason why:-
....
....

CONDITION MATRIX FOR MA/MG HEIGHT MINIMUM TOLORANCES		
ACTIVITY	**ACCEPTANCE CRITERIA**	**X / √**
1. Measure buffer height	Minimum height – 865 mm. (Measure from rail level to the bottom of buffer knuckle and add the half of the knuckle width to the measurement)	
2. Measure wheel diameter tyre thickness sizes	Minimum diam. - 984 mm or Min tyre thickness – 58mm	
3. Check securing of cow catcher	Cow catcher in place and secured	
4. Check MA/MG securing bolt and nut	Securing bolt / nut in place and locked	

"OUR FOCUS IS CONDITION BASED MAINTENANCE"

C SHED (FULL SHED) – CONSOLIDATED ELECTRICAL FITTER CHECK					
File Ref					
Creation Date	05/09/2011		Last Edit Date	05/09/2011	
Doc No. & Version	#71514v3	Author	Tino Gabryk	Page 2 of 11	
Volume and Addition	Vol. 1, 1st Addition	Approved	Dr. D Mthimkhulu		

NOTE: The entire checklist must be completed for each Motor Coach.

ACTIVITY ELECTRICAL FITTER		ACCEPTANCE CRITERIA	NOT OK / OK X / √	REMARKS AND REPAIRS TO BE DONE	REPAIRED X / √	TIME TO REPAIR MIN.
Cab:						
1	Test QSA	Max 7 seconds				
2.	Duplex Check Valve (Open)	520kPa				
3.	Duplex Check Valve (Closed)	490kPa				
4.	Drivers Brake Valve - contact fingers, wiring, free movement under vacuum conditions, handle and spider	Visual Examination				
5	Control Box	Visual Examination - No loose connection, Check that the interlock fingers are not burned, Lubrication. Locking mechanism is operating				
6.	Master Controller - contact fingers, wiring, free movement, silver tips, shunt straps and cover clips	Visual Examination Clean and lubricate contact tips.				
	- Contact Gap	3 2 mm				
	- Weight of Spring (DMF Spring 5m2a)	400g				
7.	Pilot valve - test and examine	Operational & visual examination				
8.	Meters – Calibration Date, Bent Needles, Glass	Visual Examination				
		Air Gauge		Date: /		
		Vacuum Gauge		Date: /		
		Speedo Meter		Date: /		
		Triple set meter		Date: /		
9.	- Test operation with vacuum master gauge	Yes No				
10	Siren / Hooter and foot pedal - contacts, operation, securely mounted	Clean, service and check				
11.	Pantograph operating valve – test mechanically and electrically	Operational Test				
12	Head light dimmer switch - test	Operational Test				
13.	All Cab heaters - test	Operational Test				
14	Bell and bell push switches - test	Operational Test				
15	Wiper control and motor - test and examine	Clean then Operational Test				
	- Drain water and clean water trap	No water in system				
	- Blow system clean	Clean system				
	- Check wiper blades. **Test wiper functionality with Water**	Operational with smooth, clean and clear stroke				
	- Test Electrical Wiper Motor	Operational Test				
16.	Hand brake - operation, check condition of boot and lubricate	Visual Examination, Operational Test				
17.	Train number indicator / Electronic indicator - test and examine numbers, operation of light, cover, locks and knee brace	Visual Examination and Operational Test				

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		X / √		X / √	MIN.
18. MG/MA, pressure fan, blower fan and line switch indicator lights – test	Operational Test				
19. Compressor and exhauster overload panels - test and examine - clean interlocks - interlock gaps - armature gap	Trip Test 3.2 mm (normally open); 1.6 mm (normally closed) 6 5 mm Check if calibration seal is broken Remove and Replace				
20. Lighting relay - test and examine	Operational Test				
21. Control cut out switch – examine	Visual Examination				
22. Master governor - test and examine, test rectifier	Cut-in 490 Kpa, Cut-out 640 Kpa				
23. MA / MG. overload, Low Tension contactors - compressor, exhauster. Operational Test	Contact Gap: 10 mm Min (LT Contactor) Check if cal seal is broken. Remove and Replace				
24. MA /MG contactors – examine	Visual Examination				
25. Voltage regulator 26. service, renew brushes, adjust, test and clean 27. VR cut out switch test 28. -Imfuyo type mod version	Carbon Gap: 1 2 mm Operational Test + - 90 Record version				
29. Voltage regulator cut-out switch	Visual Examination				
30. Control, heater, door positive, compressor and exhauster circuit breaker – test and examine (Trip Test)	Operational Test				
31. Field Injection Transformer (FIT)	Visual Examination				
32. Cut out switches - check springs, damage	Visual Examination				
33. Fire extinguisher – available, check if sealed, check date – securing bracket	Visual Examination Action replacement				
34. Low tension door lock - door closing properly	Operational Test				
35. Vacuum brake valve handle – working properly 36. Phase out Westinghouse Type 37. Lubricate disk with copper slip	Operational Test				
38. Compressor and exhauster overload / time delay panels – service	Operational Test				
39. Trunk radio – 110v supply	Circuit breaker operational Polarity test				
40. Antenna connections check male plug condition (5m2a)	Functional and clean				
41. Trunk radio box – Examine lock (5m2a)	Lock functional				
High Voltage Compartment:	**WAS THE HT COMPARTMENT VACUUMED??**				
42. Service locking mechanism/Lubricate bushes ensure linkage connections are properly connected 43. High tension compartment door lock,	Operational test Visual Examination Ease locking mechanism				

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prasa
PASSENGER RAIL AGENCY OF SOUTH AFRICA

ACTIVITY ELECTRICAL FITTER	ACCEPTANCE CRITERIA	NOT OK / OK X / √	REMARKS AND REPAIRS TO BE DONE	REPAIRED X / √	TIME TO REPAIR MIN.
handle (inside and outside), limit switch and interlocking – examine					
44. Blower fan circuit breakers – test and examine	Operational Test and Visual Examination				
45 Line Switches - test EP valves, examine switches and interlock fingers/contacts (sequence test). All magnet valve spindles examine and clean - Correct restrictors used - Micro data to analysis for operation - **LS 4 COUNTER READING (>18 000 Operations or regional bench mark number. Remove and replace all line switches completely)**	No Leaks, Interlock Fingers Clean. Interlock Fingers/contacts Must Make 80% Contact " knuckle action" **Check back reading =..........................** **Reading =............................**	B			
46. Combination, resistance switches and reverser - test EP valves, examine switches and interlock fingers/contacts (sequence test) All magnet valve spindles examine and clean	Operational test Visual Examination	B			
47. All HT and LT shunt straps	Visual inspection No discoloring – more than 25% - Remove and Replace and secure				
48. Dough Mould Arc chutes – Line Switches GPO3 Arc chutes – Combination and Resistance- and Field Switches	All cleaned, fitted and secured				
49. Inter Lock Box Covers and clips	All cleaned, fitted and secured				
50 Traction motor overloads – examine and set flags (Trip Manually and Reset Electrically) Operational Test Must be clean.	Check cal. Seal if broken Remove and Replace				
51. Traction motor cut out switches – examine, clean and lubricate	Operational Test				
52 Traction Motor Insulation Test - > 2mΩ	Megger Traction Motor Reading TM 1&2 . . Reading TM 3&4				
53 Current limit relay, Time Delay Relay's, Static notching relay, Power pack, Fault Locking Relay's	Operational Test				
54 DCCT – examine	Visual Examination				
55. Holding relay – examine	Operational Test				
56 CPU – Reset coach no, date and time (Only by authorized staff)	Coach number: ____ Date: ____ Time: ____				
57 - Ensure micro card retainer plates are secure					
58. - Record CPU version	Version number ____				
59 All high and low tension cables and wiring - examine	Visual Examination				
60 Snifter – isolate and test – set to 64 K.P.A	Operational test				

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ACTIVITY ELECTRICAL FITTER	ACCEPTANCE CRITERIA	NOT OK / OK X / √	REMARKS AND REPAIRS TO BE DONE	REPAIRED X / √	TIME TO REPAIR MIN.
61. Westinghouse master governor - examine	Operational test Open 620kpa Close 480kpa				
62. Earth bar connections	Visual Examination				
63 Capacitors	Visual Examination No oil leaks				
64. Flash barriers	Visual Examination Clean and secure				
65. HT Frame - examine Mounting bolts and brackets	Visual Examination Secured				
66. Air pipes - examine	Visual Examination No leaks				
Auxiliary High Voltage Compartment:	**WAS THE AUX. HT COMPARTMENT VACUUMED??**				
67 Service locking mechanism/Lubricate bushes ensure linkage connections are properly connected	Operational test				
68. MA / MG main, starting contactors and spark gap - examine, check contact gaps and wiring	Visual Examination				
69 Auxiliary no current and MA relay – examine and check contacts	Visual Examination Contact Gap: 3 2 mm (Normally Open) Contact Gap: 0 8 mm (Normally Closed)				
70 Line volt meter resistance's – Test for resistance between (only for 5m2a and micro coaches)	Step: MV9-MV1= 11550Ω MV1-MV8=2100Ω MV8-MV4=1050Ω				
71 MA / MG reset switch - test and examine	Operational Test				
72 Main high and auxiliary isolating switch - service	Visual and Operational Test				
73 Pantograph air cock and globe valve – service and test	Operational Test				
74. No current relay - examine and check operation	Operational Test				
75 Motor alternator / generator high voltage isolating switch – service	Operational Test				
76 Isolating Three Way Cock	Operational Test				
77 MA/MG 6A Fuse and Fuse Box	Visual Examination and Test				
78. Main Earth Connection	Visual Examination				
79 Metrocil (where applicable)	Visual Examination				
80. All high and low tension cables and wiring - examine	Visual Examination				
81 Compressor and Exhauster Resistor Stack	Visual Examination				
Settling Chamber:	**WAS THE SETTLING CHAMBER VACUUMED??**				
82 Switchgear, cables, bus-bars, connections covers and catches –	Visual Examination				

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			X / √		X / √	MIN.
	examine					
83	Roof through insulator and cable – examine	Visual Examination				
84.	Air equipment, Vokes filter – examine	Visual Examination				
85.	Door and locking mechanism – examine	Operational Test				
86.	Inertia filters, catches and seals – examine	Visual Examination Remove and Replace Filters				
87.	Pressure fan - examine and check / renew brushes	Visual Examination				
88.	Traction motor blowers - examine check / renew brushes	Visual Examination				
89.	Settling chamber and high voltage door interlocking mechanisms – service and lubricate	Operational Test				
90.	Settling chamber and high voltage door seals	Visual Examination				
91.	Change inertia filters	Clean filters				
Roof:						
92.	Pantograph - examine wearing strip thickness, worn knuckles and links, shunt and knuckle straps, rusted tubes, balancing gear, air leaks, panto hose, raise and lower time, weight, insulators not damaged, panto stops Check break-a-way function, pump and speed control valve Check panto raise and lowering springs Check air supply hose Measure and record copper strip thickness	Operational Test following: Inspect links for wear& tear Lubricate links Raise Time: 10 - 20 Sec Lowering Time: < 6 Sec Weight: 7 4 - 8 2 kg (Preferred 7 9 kg) Side Play (Old Type): Max 25 mm and Tighten pantograph skate horn nuts Visual Examination Strip Thickness: Min 2 mm – measure point in center of pantograph skate		Raise Time ………………..sec Lower time ………………..sec Strip thickness: _______mm		
93.	Capacitor - connections, clean	Visual Examination				
94	Hooter trumpets	Visual examination				
95	Trunk Radio aerials	Visual examination				
Body:						
96	Jumper cables and receptacles – damaged insulation, secure, electrical connections damage or burnt. Covers fitted and not damaged Cables plugged in properly and secured	Visual Examination Check for crossed 2 core cable (Bus line cable)				
97.	Air and Vacuum Dummies	Visual Examination				
Under-frame:						
98	Equalizing cocks and hoses – operation (ease and lubricate), damage, seals, air leaks	Operational Test				
99	E V V and Q S.A. valves – secure	No Pull Through QSA must work Mechanically and Electrically				
100	Exhauster - oil leaks, foundation bolts and mountings, oil tank, sight glass, coupling, silencer, pipes, check valve, brushes, commutator brush box,	Visual Examination and clean Operational Test Brush Reading (brush box				

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insulators, filter, oil feeder pipe strainer.	"A" Top brush box)					
101. Exhauster Functional Test minimum Watson disk reading 45kpa	Measure Reading ……………					
102. Exhauster hour meter reading	Yes | No			Hour reading ____________		
103. Compressor - oil leaks, foundation bolts, brushes, commutator, insulators, brush box, flex pipe, non return valve, cooling pipes.	Visual Examination Operational Test Brush Reading ……………			Brush 1 reading ……… Brush 2 ……… Brush 3 reading ……… Brush 4 ………		
104. Compressor hour counter available	Yes | No			Hour reading ____________		
105. Motor alternator / generator - H.T. brushes, L.T. brushes, slip ring, commutator, covers, centrifugal switch, brush box, connections, earth cables, mounting bolts and brackets, choke, fan covers, decals and signage Clean connection bus bar on connection box	Measure, inspect and secure all brushes. Slip ring, Comm inspect & check for defects. Covers to secure with the key Inspect for any insulation breakdown or damage Brush Reading ……………			HT Brush reading ……… LT Brush reading :- Brush 1 reading ……… Brush 2 reading …… Brush 3 reading ……… Brush 4 reading …….		
106. Exhauster, Compressor, MA/MG Commutator Condition	1 – Oily Dirt 2 - Dry Dirt 3 – Dull 4 – Light Brown 5 – Chocolate Brown	Exhauster				
		Compressor				
		MA /MG (HT)				
		MA/MG (LT)				
107. Accelerating resistors - insulators, ribbons, connections, cables, splash tray, covers, decals and signage	Visual Examination and remove and replace all temporary connections					
108. Protective and starting resistor – insulators, ribbons, connections, cables, decals and signage	Visual Examination and remove and replace all temporary connections					
109. Door and HT. reducing valve - air leaks Door water trap	Visual Examination Drain & service					
110. Main and door reservoirs - damage, air leaks, drain all reservoirs.	Visual Examination					
111. Door control relay - wiring, operation, service	Operational Test					
112. Wiper drain valve - air leaks Blocked	Visual Examination					
113. Duplex check valve - air leaks, secure (490 – 520)	Operational Test					
114 Examine shaft encoders - no damages, cables and plugs secured	Visual Examination					
115. Spirex valve to service	Operational & serviceable					
116. Safety valve – test – vent at 700Kpa	Operational test					
117 Traction motor connection boxes – covers secure	Visual Examination					
118. Earth cables and cleats	Visual Examination					
119. All Air Ducts	Visual Examination					

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120. Anti slew pins and locking nut and bolt	Visual Examination					
Bogie:						
121. Traction motor examine - brushes, brush box, commutator, v-rings, brush box arms, interconnections, gear case, arc horn, keep bolts, rotating indicator, nose suspension, earth return brush, external cables and covers fitted Inspect effect of spark caused by incorrect & non-uniform brush spring pressure, effect of high mica & rough comm. Inspect & measure brush appearance from excessive clearance holder. Clean v-rings, check comm. Discoloring	Move brush up and down (prev clogging).Ensure correct brush angle 30° to 37°.Ensure no pitting of brush face. Ensure good comm. surface WASHED AND CLEANED??		A			
122 Traction motor brush readings	Traction motor no. 1 Brush box			A B C D		
	Traction motor no 2 Brush box			A B C D		
	Traction motor no 3 Brush box			A B C D		
	Traction motor no 4 Brush box			A B C D		
123. Traction Motors Commutator Condition	1 – Oily Dirt 2 - Dry Dirt 3 – Dull 4 – Light Brown 5 – Chocolate Brown	TM 1				
		TM 2				
		TM 3				
		TM 4				
124. Bogies Assembly Inspection - axle boxes, horn stays, brake rods, safety brackets etc. - Anchor bolster bolts, bolster & rubbers - Equalizing beams, friction snubbers - Springs, primary & secondary - Anti-slew pins - Compensating links - Brake hanger pins - Spring trays - Slippers - Insulation pads - Swing hangers - Bridal rods & pins	Visual Examination	Bog 1				
		Bog 2				
125 Bolster crack examination	Visual Examination	Bog 1				
		Bog 2				

MATERIAL USED	Mark applicable item with an X		
COACH NO.	SERIAL NO.	DESCRIPTION	QUANTITY

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		Traction motor no. 1 Brush box	A		B		C		D			
		Traction motor no. 2 Brush box	A		B		C		D			
		Traction motor no. 3 Brush box	A		B		C		D			
		Traction motor no. 4 Brush box	A		B		C		D			
		MA/MG	HT Brush				LT brush					
		Exhauster										
		Compressor										
		Traction Motor Blowers	Blower fan no 1+2				Blower fan no. 3+4					
		Pressure fan										
		Voltage regulator carbon brushes										

Trade Hand - Oiling and Filters:					
126. Oil sleeve traction motors	Fill to max level (excessive leaks, refer to lifting road)				
127. Crater traction motor	Fill to max level. Ensure gearcase properly sealed. (excessive leaks, refer to lifting road)				
128. Panto skate graphite grease	2 kg				
Panto grease - knuckling and bearings	Visual Examination				
129. Exhauster oil	Fill to max. level (report excessive use)				
130. Compressor oil	Fill to max level				
131. Filters - oil bath	Fill to max level				
132. Clean filters – exhauster	Visual Examination				
133. Clean filters – inertia	Visual Examination				
134. Examine inertia filters sealing rubbers and repair	Visual Examination				
135 Oil sleeve traction motors - examine felt packs and replace if damaged	Visual Examination				

COACH NO.	EFFECTIVE REPAIRS NOT DONE PLEASE LIST AND REASON WHY

"OUR FOCUS IS CONDITION BASED MAINTENANCE"

COACH NO.	ADDITIONAL INSTRUCTIONS (MONITORING)

Important notice: It is the responsibility of the artisan shedding a motor coach to ensure that all work is done according to the required specifications and Quality standards reflected in the 5M2A Maintenance manuals.
The Technical Supervisor in charge is responsible and accountable for all work done on any coach shedded by his/her team and therefore must satisfy him / her that all work is done according to the required specifications and Quality Standards by conducting adhoc task observations.

Always observe safety rules and regulations.

It is the responsibility of the Quality Assurance representative and maintenance service team to ensure the technical cleaning is effective and executed on the maintenance specific areas identified.

Grade	Surname & Initials	Signature	Date
Tech. Supervisor			
Electrical Fitter			
Trade Hand			

CHANGE LIST			
Item Reference Number	DESCRIPTION OF CHANGE	PAGE	DATE OF CHANGE
No.1	Changed logo back to Metrorail	1 - 10	30/07/2009
No. 2	Added mission critical measurement categories	7&8	30/07/2009
No.3	Added compressor and exhauster hour meter readings	7	30/07/2009
No.4	Reviewed Supervisor role and responsibility	10	30/07/2009
No.5	Enriched Supervisor duties	1&10	15/09/2009

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No.6	Removed Sun visor test and repair. Added to Vehicle builder check	2	15/09/2009
No.7	Removed Roof steps/catwalk. Added to Vehicle builder check sheet	6	15/09/2009
No.8	Removed Gummies. Added to Vehicle to builder check sheet	6	15/09/2009
No.9	Amended Watson disk reading from 450 kpa to 45 kpa	7	15/09/2009
No. 10	Removed door and HT reducing valve. Added to Sliding Door sheet	7	15/09/2009
No. 11	Removed water trap. Added to Sliding door check sheet.	7	15/09/2009
No. 12	Removed door control relay. Moved to Door check sheet	8	15/09/2009
No.13	Removed Chief Electrical fitter	10	15/09/2009
No.14	Added LS Check back reading	4	15/09/2009
No. 15	Added condition matrix for MA/MG height minimum tolerances	1	01/10/2009
No. 16	Removed Activity 107 MA/MG height measurement	7	01/10/2009
No. 17	Removed Activity 98 cow catcher examination.	6	01/10/2009
No. 18	Reviewed process followed to test Pantograph air supply	1	03/11/2009
19.	Changed logo to PRASA logo	All	17/01/2011
20.	Included Dr. in Authorized person designation	All	17/01/2001
21.	Added raise and lower time to be provided – item no. 92	7	03/09/2011
22.	Removed Trade hand light checks	9	03/09/2011
23.	Added mission critical components cut out question.	1	03/09/2011